State Water Survey Division

Illinois Department of
Energy and Natural Resources

Miscellaneous Publication 81

MEAN TEMPERATURE BIASES AS A FUNCTION OF THE TIME OF OBSERVATION

by

David E. Head

North Central Regional Climate Center
Illinois State Water Survey
Champaign, Illinois 61820

NCRCC Paper No. 6

Partially Supported by
National Climate Program Office
NOAA/NA81AA-D-00112

February, 1985

TABLE OF CONTENTS

ABSTRACT

Hourly and daily temperature data for ten National Weather Service stations in the Midwest and upper Great Plains states were used to determine long-term time of observation biases on mean temperatures derived from 24-hour maximum and minimum values. Although differences in the magnitude of the bias were found from station to station, good continuity was exhibited across the area in question. Generally the biases for any given month show a stronger longitudinal than latitudinal correlation. Daily mean temperatures calculated from 24-hour readings made near 0700 local time tend to be lower than a midnight-to-midnight reading. Observations made during the afternoon tend to be higher, with magnitudes of 0.5 C to 1.0 C common.

Station biases tend to be correlated strongly along latitudinal lines. Possible climatological factors for the geographical distribution of the biases are discussed.

ACKNOWLEDGMENTS

I would like to thank the North Central Regional Climate Center, located at the Illinois State Water Survey in Champaign, Illinois, and Mr. John Vogel, Director, for scientific and financial support for this project.

I would also like to thank my advisor, Dr. Wayne Wendland, Illinois State Climatologist, for the invaluable help and encouragement he provided from the conception of this work. The comments and suggestions of my committee, Dr. Thomas Frank, Dr. Scott Isard, and Mr. John Vogel, are greatly appreciated. Their experience and insight helped to focus the discussion. My thanks to Lisa Appleton Miskimen for her considerable effort in editing and compiling this manuscript. Her aid and assistance in my absence made the completion of this thesis possible. The following state climatologists supplied data used in this study: Indiana - Dr. James Newman; Iowa - Dr. Paul Waite; Kansas - Dr. L. Dean Bark; Michigan - Dr. Fred Nurnberger; Missouri - Dr. Wayne Decker; and North Dakota - Dr. John Enz.

Finally, I would like to give thanks to the Lord, without whom I would never have attempted graduate school nor this thesis; and my wife, Beverly, the immediate reminder of God's love and support for me through these years.

CHAPTER 1

INTRODUCTION

When using climatic data to compare one weather station to another or to analyze for statistical stability, the data must be as error-free as possible. More specifically, when temperature series from an individual or a group of recording stations are used in research, any nonclimatic errors or biases in the record must be removed. This is particularly important when possible changes are of similar magnitude, or less than those due to possible error.

The recommended time for recording maximum and minimum thermometers is at midnight (Glossary of Meteorology, 1959). If temperatures are recorded only every hour, the highest and lowest of these values typically only agree with the actual extremes within 0.6 C (1.0 F) about 70 % of the time and within 1.1 C (2.0 F) about 95 % of the time (Mitchell, 1958). The hourly temperatures <u>always</u> lie closer to the daily mean and thus underestimate the extreme temperatures.

The daily mean temperatures for National Weather Service (NWS) cooperative stations are currently computed from the daily maximum and minimum readings from maximum-minimum thermometers, read at some hour convenient to the observer. The cooperative observer visits the instruments once every 24 hours, recording the maximum, minimum, and current temperatures. This daily mean is the basis for most historic temperature records of various period means. The mean temperatures for a given station may contain accumulated errors due to the temperature measuring instrumentation itself, its location, observer error, and may contain an error component due to the time at which observations are made. Much work has been done concerning the biases introduced into temperature records by varying instrument type, location, and the method of computing the means (e.g., see Bigelow, 1909; Hartzell, 1919; Mitchell, 1953, 1955, 1961b; Thorn, 1966; Nelson et al., 1979). Mitchell (1953) provides an extensive list of the errors and additional references. Correcting data for the time of observation discrepancy, in particular, has generally been avoided. Yet, as Schaal and Dale (1977) pointed out, it can be a substantial error, since it may cause spurious spatial and temporal anomalies in historical mean patterns. Also, this bias clearly adds to the already complicated systematic errors previously mentioned, thus increasing the variability within climatological records. Hence, when different records of various stations, each with its own individual mix of observational variability, are combined for use in research, the error variance introduced could be as large as the prediction error for some modeling purposes (Dale *et al*., 1983).

It is generally known how this bias occurs. For example, if a cooperative observer takes the reading near the time of the maximum temperature of a given day, say at 1600 hours, that maximum will be recorded for that day and also for the next day, assuming the actual maximum the following day is lower than that of the previous day and/or that it occurs later than the next day's observation. Minimum temperatures would be recorded twice for the same reason, if the observations were taken near the time of minimum temperature occurrence. However well known the reasons for the occurrence of the bias, it is not clear what factors contribute to the sign and magnitude of the biases at any given location; or how they may vary over a region by season, elevation, latitude, longitude, and percentage possible sunshine (i.e., cloud cover).

Assuming that the time of observation bias is a systematic error (Mitchell, 1958; Baker, 1975), it can be evaluated, and observations may theoretically be corrected. Although Mitchell (1961) and Nelson *et al*. (1979) discussed methods of removing most of the discrepancies from climatological means, no synoptic scale study of the time of observation bias has yet been completed and no correction factors based on more than just a few years have been derived.

Thesis Objectives

In consideration of the potential error in daily, monthly, and longer mean temperatures as a function of time of observation, the following investigation has these specific goals:

1. To determine the mean biases from long-term observations introduced into daily mean temperatures for the Midwest and high plains with data from National Weather Service (NWS) first-order stations (24-hour stations with continuous observation of temperatures).

2. To develop a qualitative climatology for, and describe the geographical or spatial distribution of, the biases.

CHAPTER 2

LITERATURE REVIEW

Historical Development of Bias

Nichols (1934) cites the first published report on the effect of the time of observation on maximum, minimum, and mean temperatures by W. Ellis in 1890, using four years of data at the Royal Observatory at Greenwich, England. Later C. A. Donnel (1912) derived the differences in the average monthly maxima, minima, and means from one year of data (1911) between observations taken at 0800, 2000, and at midnight for Des Moines, IA. He noted lower and higher monthly means for the morning and afternoon readings, respectively, relative to those taken at midnight. Hartzell (1919) found that daily means computed from maximum-minimum temperatures recorded at a particular hour (specifically, 1200, 1700, 2000, and midnight at Fredonia, NY) were seldom the same as the "true" daily mean derived from a thermograph. Nichols (1934) addressed the questions of frequency, magnitude, and importance of such discrepancies in the records of three south Texas field stations for winter months over the three years in 1931-34. In addition, Rumbaugh (1934) compared monthly means computed from daily maxima-minima where the day ended at 0800, 1700, and sunset for a period of six years at Twin Falls, ID. Maxima and minima were extracted from thermograph record-sheets for each 24-hour period. He found that means determined from morning observations were close to Weather Bureau (now National Weather Service) midnight-to-midnight means; whereas the afternoon readings were always higher. Eight NWS first-order stations located in diverse climatic regions of the U.S. were examined by Mitchell (1958) to identify the typical range of errors introduced by changing observation times. He used two years of hourly data for alternating months beginning with January to represent the different times of observation, finding that the magnitude of the errors were somewhat different for the eight stations. The greatest difference between errors ranged from 0.2 C (0.3 F) in July at Tampa, FL to a maximum of 1.9 C (3.4 F) in January and November in Austin, TX and in March at Columbus, OH. He attributed these differences to local climatic and seasonal factors.

Articles that followed those above stressed the effect that time of observation had on climatic information. Baker (1975) described the use of hourly temperatures for a three-year period at St. Paul, MN, to derive mean biases for each hour of the day. He noted the cumulative effect these errors had upon growing-, cooling-, and heating-degree days. Another important study by Schaal and Dale (1977) pointed out possible erroneous conclusions concerning climatic change introduced by data from different times of observation at cooperative stations in Indiana. Nelson et al. (1979) developed a method for removing non-climatic variability from monthly means. Their technique standardized regional records (in this case the climate divisions of Indiana from 1930 to 1976) to a base year, i.e., 1976, in an effort to eliminate the errors introduced by changes in the time of observation, station location, instrumentation, and observer. Blackburn (n.d.) summarized the effect of changing observation time. He pointed out that an often-forgotten problem arises at the end (beginning) of a month when the last (first) temperature of the series may not be a day within the month in question, depending on the time of observation. This error is potentially greatest during spring and fall.

Obvious and Nonobvious Causes

The official National Weather Service method to determine the mean temperature for a given day is to add the daily maximum and minimum and divide the sum by two. This has been typically accomplished at NWS first-order and cooperative weather stations for all of this century (Schaal and Dale, 1977). A better time-weighted estimate of the area under a daily temperature curve would be to determine the mean of the 25 hourly temperatures recorded, including both midnight readings. For any given day, the differences between the average of 25 hourly temperatures and the maximum-minimum average (determined from any hour) may be as much as several degrees (Schaal and Dale, 1977). This is dependent on the hourly temperature departures from the normal diurnal temperature curve for that date. However, as Baker (1975) and Mitchell (1958) found, the mean temperatures based on daily means computed from the maximum and minimum correspond closely to means calculated from averaging the 25 hourly temperatures. This is true, however, only if the day over which the maximum and minimum are recorded ends at a time coincident with the last of the 25 hourly observations (midnight). Means calculated from a 24-hour period ending at other times than midnight may differ from the hourly averaged means by as much as 1.1 to 1.7 C (2 to 3 F) (Schaal and Dale, 1977).

Daily means computed at first-order NWS stations are derived for the day ending at midnight, whereas cooperative station observations are taken at some time between 0600 and 0800 or 1600 and 2000 Local Standard Time (LST). Other operational stations recording rainfall, river flow, etc., usually take temperature readings between 0700 or 0800 LST. The times selected in the latter two cases are those which are convenient for the observer. When temperatures are gathered from the above sources, the variations in observation times can introduce errors into spatial analyses of mean data. These errors can be positive or negative, thus reducing or elevating the actual mean temperatures. This will readily be seen later.

Another source of discrepancy can be attributed to biases introduced by making an observation at, say, 0700, regardless of whether Daylight Savings Time or Standard Time is currently in force; or by observational and computational rounding errors. Cooperative station records can be further confusing when an observer changes the observation time indiscriminately (e.g., on a given day an observer takes readings at 0800 instead of the usual time of 0700). As Schaal and Dale (1977) stated:

> Biases from other sources, such as station moves, city encroachment and change of equipment,...may be the main cause for heterogeneity in a single station record. The time of observation bias, however, is a more insidious and [perhaps] consistent bias which has to be taken into account in any historical study of environmental changes. [p. 221]

It is obvious that any errors introduced by time of observation of temperature are integrated into the historical weather data and, hence, monthly and annual means (e.g., the "normals" as defined by the World Meteorological Organization).

Although the root of the observation time problem has been discussed by the preceding authors, a review may clarify certain subtleties. Following Schaal and Dale's

(1977) example, assume a temperature curve for three days (April 30, May 1, and May 2) of the form shown in Figure 1. If maximum and minimum thermometers were read and set at, say, 0700, 1700, and midnight, then the maxima and minima would be recorded as shown in Table 1. Obviously, the 0700 observation would typically record the maximum temperature from the previous day. In a few cases the maximum could occur after midnight but before 0700. Note that on May 2, the maximum is "carried over" from the previous day, resulting in a 1.7 C (3 F) error from the "correct" midnight-to- midnight reading. Also, it can be seen that the minimum recorded for May 1 is really the minimum from April 30.

Maximum and minimum temperatures on the final day of a month can also cause a significant error. For example, using an April 30 high temperature recorded at 0700 on May 1 will likely introduce a negative bias, since in most cases the April 30 maximum will be lower than the following May 31 maximum (Blackburn, n.d.).

Many of the above-mentioned authors note that the magnitude of the bias varies according to the time of year (length of daylight), and frontal passage frequency. Blackburn (n.d.) summarizes the effect these two variables have on the error by suggesting that the total monthly discrepancy is proportional to the average day-to-day variation in the temperature extremes. Those months with

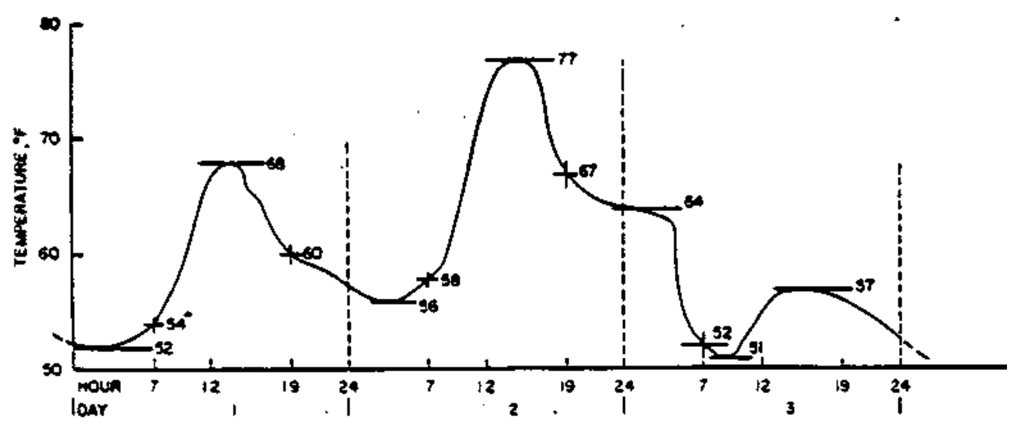


Fig. 1. Typical three-day continous thermogram. Significant temperatures were entered to demonstrate recording temperature extremes for different observational days shown in Table 1 (after Schaal and Dale, 1977).

Table 1. Maximum and minimum temperatures (°F) read from maximum and minimum thermometers at indicated observation times shown in Fig. 1.

Station Observation Time (hours)	Temperature Extremes	Date Apr11 30 (day 1)	May 1 (day 2)	2 (day 3)
2400	Maximum	68	77	64
	Minimum	52	56	51
1900	Maximum	68	77	67
	Minimum	52	56	51
0700	Maximum		68	77
	Minimum	52	56	52

frequent frontal passages have higher variations in day-to-day extremes. Mitchell (1958) observed that the individual curves closely resemble the curves of diurnal temperature change (see his Figure 1). This would certainly imply a connection with day length. In addition, he found high correlations between the sum of the largest positive plus negative biases for a month, and the following three variables: 1) mean daily temperature range, 2) mean cloudiness, and 3) mean interdiurnal temperature change. However, he did not provide information about how they correlated, or the strengths of these correlations. These relationships will be more fully discussed in Chapter 4 of the present study.

Although an attempt was made by the preceding authors to discuss the significance of the time of observation discrepancy, and in some cases to provide corrections, many of their conclusions were found to be inadequate because of insufficient resources (i.e., too few stations, too short a data period, lack of computing facilities, etc.). Also, little attempt was made to link forcing factors (i.e., time of year, cloudiness, etc.) to the direction and magnitude of the biases. As Mitchell (1958) stated best:

> All these [previous] studies have involved either a very limited geographical area or a very small choice of observation times, or both. This fact rather precludes useful quantitative generalizations of the influence of observation

> time on derived mean temperatures. Moreover, it was the general intent of the foregoing authors to evaluate the extent of incompatibility between the mean temperatures of different stations wrought by grossly dissimilar observation times at each, or to select an observation time which approximates the true 24-hour mean better than certain other times. [pp. 83-84]

The above was also true for those studies that followed that of Mitchell.

Of all previous work reviewed, only Mitchell presented some geographical coverage and climatic diversity (eight stations) for the U.S. of these factors for all observational hours. However, he used a relatively short record (two years) for each station and considered only alternating months beginning with January. Also, he acknowledged that limiting the study to only these "...eight stations used in [his] study are obviously inadequate to define the effect at all other stations by geographical interpolation" (Mitchell, 1958: 87). His intent was to reveal the effect that the time of observation bias would have on the homogeneity of a station's climatological temperature record.

When short time series of climatic data are used in calculating means (in this case mean biases), the variance of extremes in such a record can skew the averages so as to make them unreliable for use in analysis, modeling, or research. Obviously, for some degree day-based models and other weather-crop yield models, where temperature averages are critical, a long series of data is necessary (Dale *et al*., 1983).

Effects on Temperature Records and Models

Schaal and Dale (1977) showed that temperature-derived variables can be affected by the time of observation bias. Since these variables (e.g. heating-, cooling-, and growing-degree days) are cumulative measures of the difference of mean temperatures from some base temperature, the resulting totals of one observation time can deviate by hundreds of degree days from that of another time. They found that degree days based on 0700 observations as opposed to those at 1500 differed by 10 per cent at Indianapolis from two years of March data. This error would be unacceptable for long-range planning of fuel needs of the heating and air conditioning industry. Baker (1975) found similar results for his three-year study at St. Paul, MN. Applying mean temperatures with biases to two weather-management crop yield models, Dale *et al*. (1983) found that temperature-caused simulation errors, although nontrivial, contributed a relatively small part of the total variance in the models.

Schaal and Dale (1977) also noted that a perceived gradual cooling of the climate of Indiana between 1935 and 1975 was primarily due to the change of the majority of cooperative stations' observations from afternoon to morning. The state mean was reduced 0.7 C (1.2 F) solely from a change in the time of observation. Artifacts in a record, like these, can be as great as the actual climatic variation (Mitchell, 1953). Needless to say, comparison of individual stations in the same region could show opposing climatic changes, and individual records, or areal means, could be unrepresentative for other areas.

The consensus of all of the previously mentioned authors reveals that means for any period calculated from late morning, afternoon or evening observations were greater than midnight-to-midnight means; and morning means were lower. In addition, the greatest positive deviation was found to be larger than the corresponding negative anomaly. Mitchell (1958) and Baker (1975) observed that the greatest negative bias was found from observations following the hour of sunrise; whereas the largest positive error tended to occur from observations between 1400 and 1600 LST (the usual time of daily maximum temperature occurrence). Mitchell (1958) showed that the deviations were smaller from maritime locations (in his study, Tampa, FL); and larger for continental sites. As inferred earlier, this is clearly a reflection of a station's regional climate. Researchers generally noted that the magnitudes of the above biases were greatest in the winter and least in the summer. This is most likely due to the higher frequency of frontal passage during the former.

In conclusion, for the purpose of deriving corrections and developing an adequate climatology of the time of observational bias, the above studies were found to be, in part, lacking sufficient time series and/or areal coverage. Both conditions must be met to achieve the objectives previously stated.

CHAPTER 3

DATA AND ANALYSIS

In order to meet the objectives stated, a relatively long time series (at least ten years) of quality daily maximum-minimum temperatures and hourly temperatures (all hours) at stable locations was needed for the computation of long-term biases. Quality in this context meant the use of reliable instrumentation to measure the temperature values, resulting in relatively few missing data. Hence, a selection of ten first-order NWS stations was used in this study according to the following conditions:

1. To provide reasonable coverage of the Midwest and high plains states shown in Figure 2.
2. Hourly temperatures and daily maximum-minimum temperatures were available for each station in digital form for at least ten years during the period 1948-1964.

Data from Bismarck, North Dakota; Des Moines, Iowa; Dodge City, Kansas; Flint, Michigan; Indianapolis, Indiana; Peoria, Illinois; Rapid City, South Dakota; Sault Ste. Marie, Michigan; Springfield, Illinois; St. Cloud, Minnesota; and St. Louis, Missouri were used in this study. Hourly temperatures were often not digitized for the years

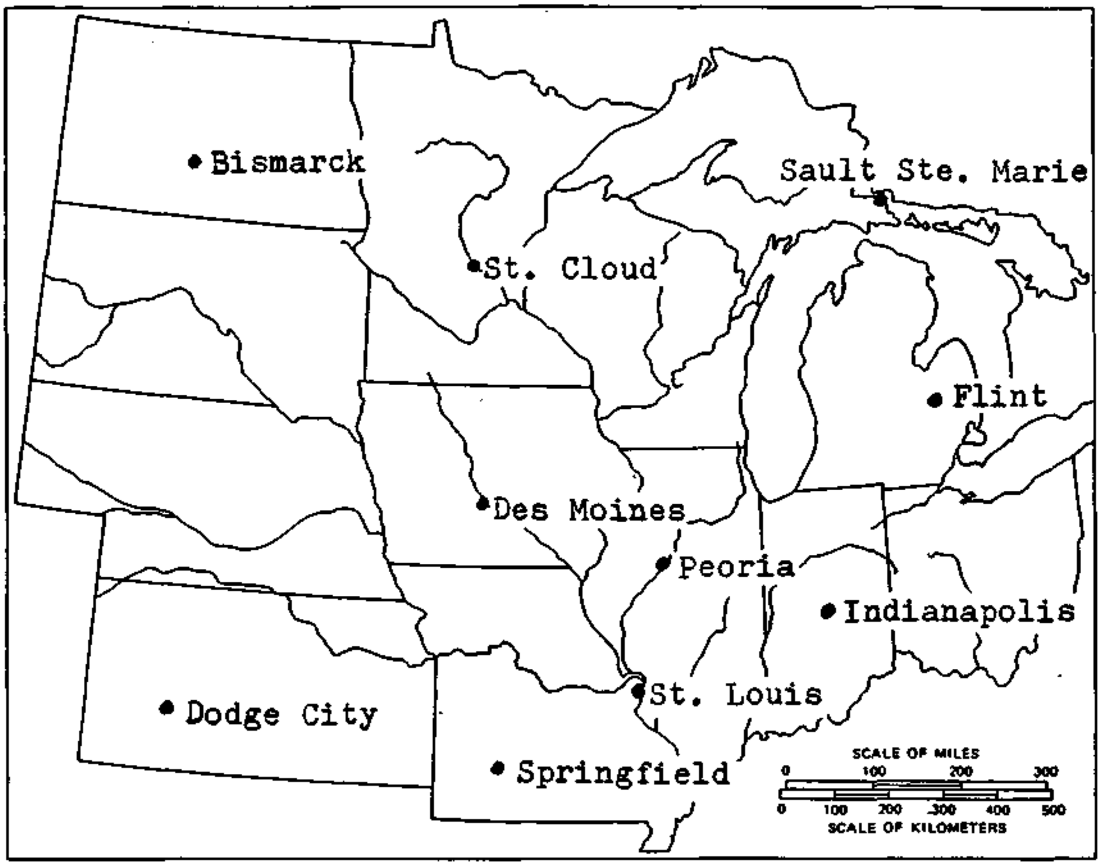


Fig. 2. Midwest and high plains states along with the stations used in this study.

before 1948. Also, the record of most first-order NWS stations after 1964 was restricted to only three-hourly data (Changnon, 1975). Thus, the computations were limited to the years specified for each station, but generally 1950 to 1964. Missing values in the hourly data were interpolated using a four-point Lagrange linear interpolating scheme. If more than six successive values were missing in any given sequence of 14 temperatures, that day was not used in the calculations. This only occurred for one day at one station. The vast majority of missing temperatures were isolated to single hours. If any extremes were missing from the daily maximum-minimum record, that day was deleted from the analysis. Care was taken to account for the exact number of missing readings. Table 2 shows the list of stations and their respective length of record used, elevation, latitude, longitude, and the number of missing data. Missing data accounted for less than 0.1 % of any data set. Most stations' hourly records were continuous (except for missing data), at least from 1950 through 1964. An exception was the record at Peoria, IL, where the years 1952-56 were not used because only three-hourly data were available. Consequently, the daily record for those years was also excluded.

The mean of the highest and lowest hourly temperatures (highest plus lowest, divided by two) in the 25 hours ending with each hour of the day was calculated for each day at

Table 2. Station locations, the years covered by the data, and the number (#) of missing values.

Station	Years Covered	# Missing Hourly	Data Daily	Latitude[1]	Longitude[1]	Elevation[2]
Bismarck	1950-64	8	0	46	100	1650
Des Moines	1950-64	21	0	42	93	940
Dodge City	1950-64	11	2	37	100	2580
Flint	1950-64	8	0	43	83	750
Indianapolis	1950-64	114	0	39	86	790
Peoria	1950-64 & 1957-64	26	0	40	89	650
St. Cloud	1950-64	11	*	45	94	1030
St. Louis	1950-64	7	0	38	90	540
Sault Ste. Marie	1950-64	1	0	46	84	720
Springfield	1950-64	59	1	37	93	1270

*Not available

[1]Whole degrees

[2]Nearest tens of feet

every station for the period 1950-64. This meant that for all ending hours at least some readings were retained the preceding calendar day. Hence, December 31, 1949 readings were included. These calculations were made to simulate means derived from maximum-minimum thermometer observations made at any of the 24 hours of a day. Also, daily means were computed using the actual daily maximum-minimum temperatures for the same period. Fifteen-year means (ten-year means for Peoria) were then derived for each month using the above 25 series of daily means. So, the 15- (or 10-) year means derived from the hourly temperatures for any given observation hour were defined as:

$$\frac{1}{D}\sum_{i=1}^{D}\left[\frac{\max T_h + \min T_h}{2}\right]_i , \quad h=1,2\ldots 25 \qquad 1),$$

where,

D = the number of days in the 15- (10-) year period,

max T_h = maximum of the 25 hourly temperatures,

min T_h = minimum of the 25 hourly temperatures. The 15- (10-) year means computed from the daily maximum-minimum were defined as:

$$\frac{1}{D}\left[\frac{T_{max} + T_{min}}{2}\right]_i \qquad 2),$$

where,

T_{max} = maximum temperature for day i,

T_{min} = minimum temperature for day i. See Appendix B for the Fortran 5 programs used in this study.

Three sets of monthly mean temperatures were then defined from the series of 25 observation means. Means calculated from the daily maxima-minima were termed the true means. Those means that were derived from hourly readings where the day ended at midnight were defined as midnight means. The means from the hourly readings with the day ending at any hour of the day were called hourly means.

A set of comparisons was then made. For each month the difference between the hourly and midnight means was computed. The differences were defined as the former minus the latter. These differences, or biases, formed the basis for the correction factors.

In order to evaluate how the biases changed over time for each station, the following plots were made:

1. For each month:
    1. A graph showing the bias for each hour of the day (e.g., see Appendix A, Figures A1-A10). These were evaluated to determine the individual observational hour biases fluctuated through the months.
2. For the year:
    1. A graph with the biases from observations at the hours 0500, 0600, 0700, 1500, and 1900 for each month (e.g., see Figure 16). This was done to determine a seasonal component in the biases of typical cooperative station observation times and those hours generally near the warmest and coolest times of day.

2. A graph showing the maximum positive and negative biases for each month (e.g., see Figure 5). These were made to determine if any trends or similarities existed in the extreme biases over the year.

Maps of the bias at various hours at all stations were made to assist in determining the geographical distribution over time (i.e., within a month and between months or seasons). See Figure 36 for an example. The hours chosen were selected to provide: 1) one observation every three hours (0300, 0600, 0900, 1200, 1500, 1800, 2100), 2) coverage near the time of sunrise (0500-0800), and 3) coverage near the time of day when the maximum temperature generally occurred (1400-1600). For all hours except 0600 and 1500 in numbers 1-3 above, only maps for the months centering on each season were made (i.e., January, April, July, and October). The maps helped to determine the spatial uniformity of biases which could yield regional correction factors. The relationship of biases to latitude, longitude, elevation (above mean sea level) and percent possible sunshine are also possible from these maps.

The stations were divided into three groups according to a range of nearest whole latitudes: high latitude, 44-46 N; mid-latitude, 40-43 N; and low latitude, 37-39 N. This was decided after a preliminary review of Figures 5-14, which showed the greatest positive and, to a lesser extent, the negative bias curves to have one of three general patterns and magnitudes. The values from each station's greatest positive and negative bias curves were separately normalized to reduce any longitudinal variation. Normalization of the greatest positive or negative biases was defined as:

$$(GB_i - \overline{GB})/SDGB \qquad 3),$$

where, for a given station,

GB = greatest bias at month i,

$\overline{GB}$ = mean of the greatest biases for all months,

SDGB = standard deviation of the greatest biases for all months.

This was done in an attempt to determine a relationship within and between the three groups of stations. Also, a comparison as to when extreme biases occurred within each group could be made while holding latitude constant. Averages of each group's curves were calculated along with an average of all groups.

To determine the range of biases for varying lengths of the record, the biases of the months January, April, July, and October (the central months of the seasons) were calculated over one, two, four, and eight years for Peoria. These were compared to the ten-year biases previously computed for this station.

As inferred earlier, the best estimate for the mean temperature for a day is the sum of 25 temperature readings divided by 25. Another estimate, although one that does not weigh all hours, is to add the maximum and minimum temperatures found in the 24-hour period and divide by two as in Equation 2 above. Since the accepted method of deriving period means at NWS first-order and cooperative stations is from daily maxima and minima (Equation 2), differences were calculated between the midnight means (Equation 1) and the true means (Equation 2) for the same periods previously given at each station with the exception of St. Cloud.

At seven of the stations (Bismarck, Dodge City, Flint, Indianapolis, Peoria, Sault Ste. Marie, and Springfield), the magnitudes of the biases between the (hourly) midnight and true means across all months were zero. However, the biases ranged in magnitude from 0.1 C (0.2 F) to 1.3 C (2.3 F) for all months at St. Louis.

It is possible that those stations with no biases across the months were using maxima and minima determined from the hourly records as a substitute for the "actual" daily extremes, where the latter were read from a thermograph trace or maximum-minimum thermometer. The use of hourly extremes instead of intrahourly values was the recommended method for Air Force-trained observers (U.S. Government Printing Office, 1964).

A sample of daily extremes from hourly temperatures from eleven stations were compared to the corresponding (by date) daily maxima-minima used in the analysis and to the published daily extremes. It was found that all of the values at the seven zero-bias stations agreed (i.e., the daily extremes were the same as the hourly extremes). However, at St. Louis, individual hourly extremes deviated from the daily maxima-minima by zero to 1.1 C (2.0 F), but always in the expected direction, i.e., hourly maxima were equal to or lower than daily maxima and hourly minima were equal to or greater than daily minima. The daily extremes used in the analysis for Des Moines were found to be inconsistent with published daily maxima-minima. Therefore, no comparison between midnight means and true means could be made at this location. Despite the larger magnitudes at St. Louis (Figure 3), it appears that this was the only station in which biases from the true mean could be assessed. Mitchell (1958:. 85) and Baker (1975: 472) state that only a minor difference exists between midnight-to-midnight means calculated from hourly extremes and corresponding means from the daily maxima-minima (from a hygrothermograph). Mitchell found this difference to be less than 0.2 C (0.3 F) in monthly means, with the hourly extreme's range underestimating the daily range by less than five per cent at Elmendorf Air Force Base, Alaska. Baker's (1975) analysis showed that the magnitude of these biases varied unsystematically and never exceeded 0.2 C (0.3 F) in the

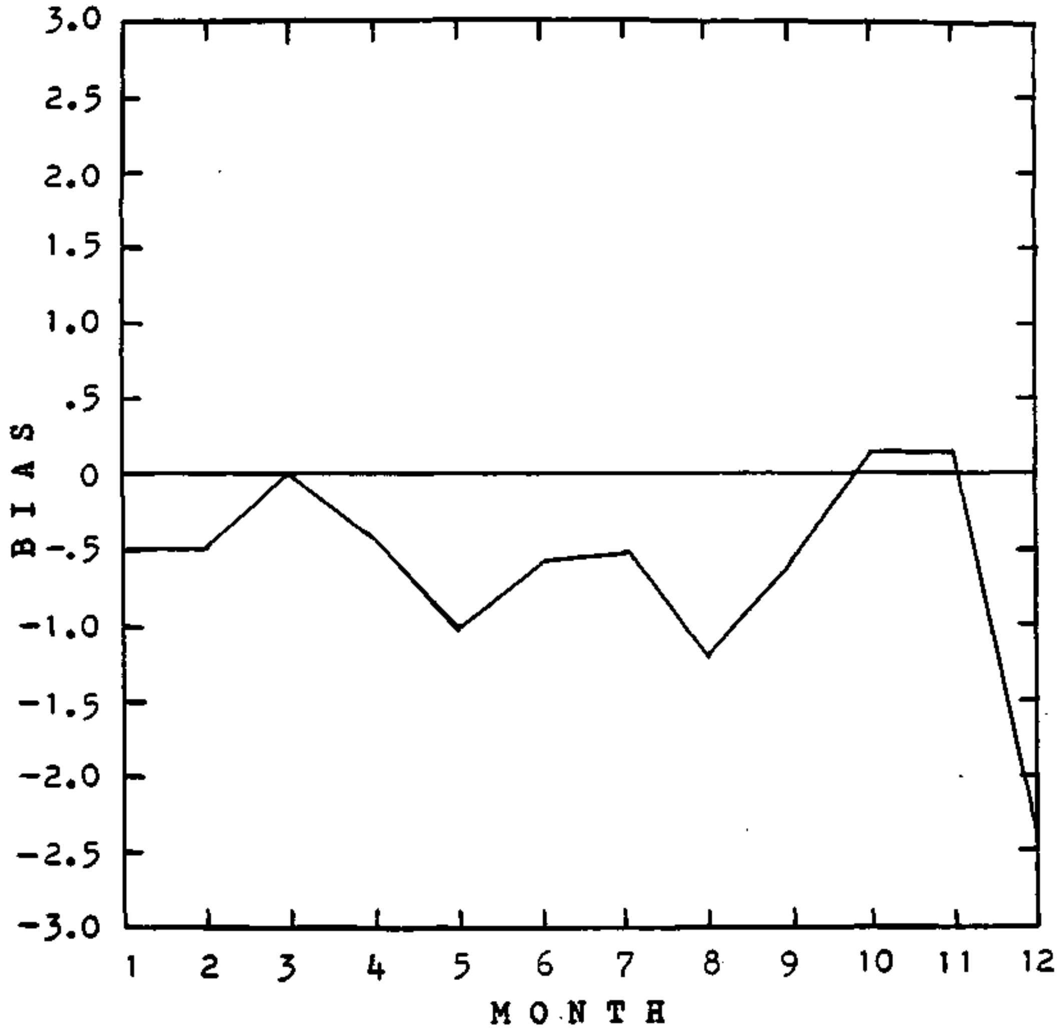


Fig. 3. Monthly differences between hourly means and daily means for 2400 hours at St. Louis. (°F)

former and 0.3 C (0.5 F) in the latter. Hence, the magnitude of the biases as calculated above should vary only slightly or not at all from biases in means (except at St. Louis) derived from separate maximum-minimum thermometers read once a day at a given hour. Thus only differences in biases between hourly and midnight observations were completed, displayed, and discussed. Biases between the midnight and true means (though small in magnitude) could be added to the hourly biases to arrive at the deviation of hourly means from true means.

CHAPTER 4

RESULTS

To illustrate the general results, biases at each hour and month are graphically presented in Appendix A, Figures A1-A10. Figure 4 presents the biases for Des Moines, which are representative of the shape of the hourly bias curves for the group. Means generated from readings beginning at hours between 0100 and approximately one to three hours after the time of sunrise are generally lower relative to the midnight-to-midnight means (negative bias). Those means from the remaining hours are higher (positive bias). The obvious exclusion is where the curves cross the zero bias line. As stated earlier, the sign and magnitude of the bias at any hour are related to the number of carryover maxima or minima from one day to the next, thus raising or lowering, respectively, the resulting monthly means.

The feature most readily noticed in Figure 4 is the nonsymmetric distribution of the positive biases versus negative biases. The area under the negative bias side of the curve increases in size from November to March with the largest bias following the time of sunrise. It then decreases from March to November. In a few cases, the

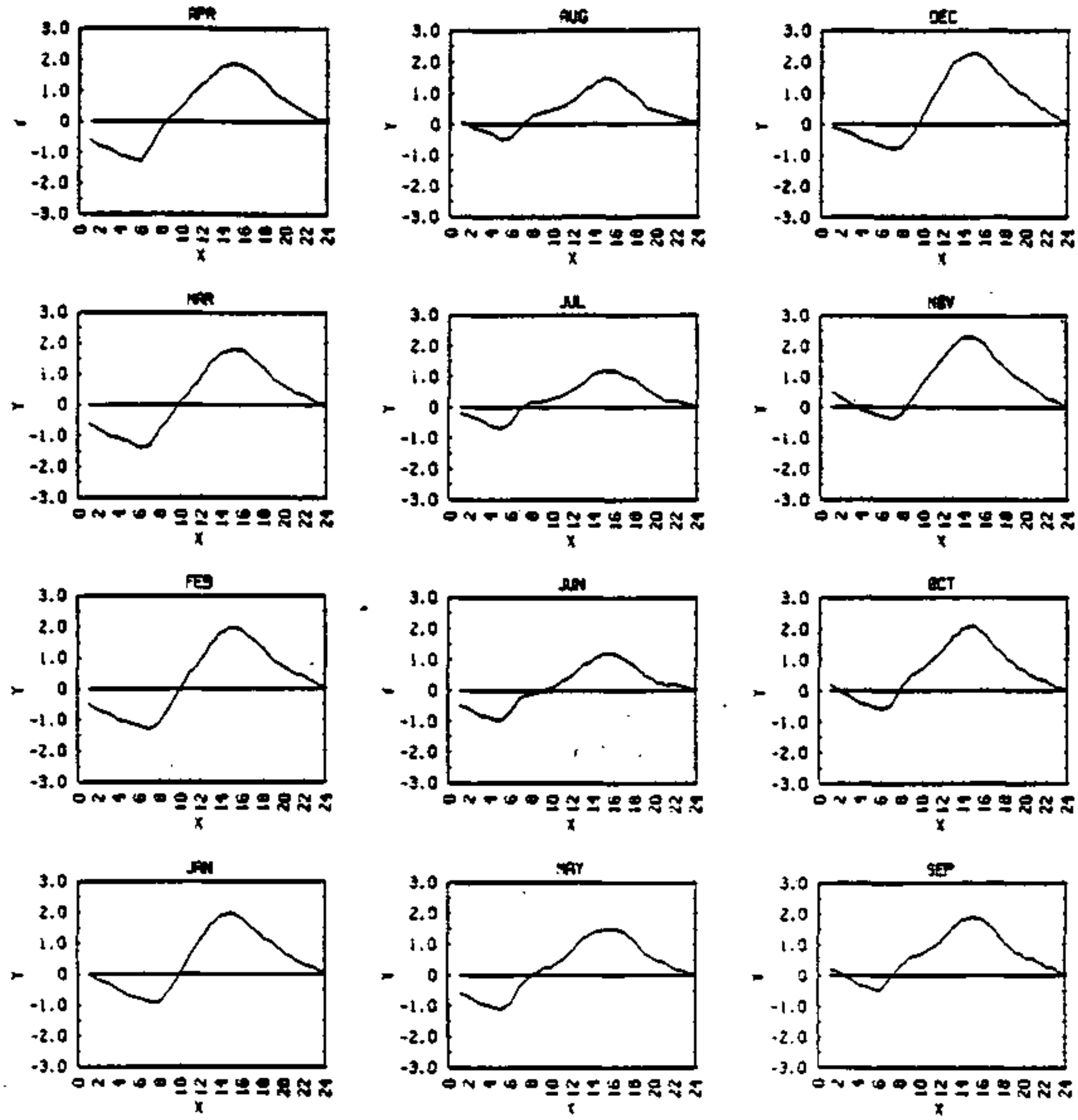


Fig. 4. Biases for Des Moines are representative of the shape of the hourly bias curves for the group. Hours of the day along the X-axis and bias (°F) along the Y-axis.

biases for 0100 and 0200 are positive. This is due to a more frequent occurrence of previous-day maxima carryover for these hours and months.

Minimum bias generally occurred within an hour of sunrise, whereas maximum bias tended to occur near the time of maximum temperature. With the rapid rise of the bias to zero deviation approximately two hours after the minimum (maximum negative bias) till the maximum (maximum positive bias) and then decreasing thereafter. The resemblance of the curves to the diurnal temperature curve is expected since the most negative biases for a given month should occur near the theoretical time of minimum (i.e., most minima carryover) and the largest positive bias should occur around the time of the maximum. In Figure 4, the areas between the curve and zero bias where negative biases occur are smaller than the corresponding area under the positve bias curve since temperatures near a day's normal minimum are more nearly the same from day to day than those near the maximum. Landsberg (1966) showed that the interdiurnal variability of minimum temperatures was generally smaller (for January and July 1957-1961) than for maximum temperatures. Thus, even though minimum carryover dominates the early morning readings, the frequency of minimum carryover year round is relatively less than that of maximum carryover for late morning and afternoon to evening hours. The overall effect is to raise the bias curves slightly.

Greatest Positive and Negative Bias

Figures 5-14 show the greatest negative and positive biases for each month. The greatest positive and negative bias curves are similar in shape for most stations, i.e., minimum and maximum positive bias centering on July and October-November. Sault Ste. Marie was an exception, reaching its maximum in May, minimum in March or December, with a secondary minimum in August. Also, while most of the stations' minima in the greatest negative biases occurred in March, Sault Ste. Marie reached a minimum in February. Clearly, the latter station's biases are affected by its proximity to Lake Superior.

For most stations the largest magnitudes of greatest negative and positive biases occurred around March and November, respectively. Baker (1975) states that the former is attributed to the fact that temperatures in this month are increasing at the maximum rate for the year. Thus, when readings are taken at a given hour near the morning minimum (i.e., the negative bias), the minima at the beginning of March are generally much lower than those at the end of the month, as compared to all other months. Hence, the minimum recorded for a given day is more frequently the minimum for the previous day in addition to the normal carryover tendency for morning readings. The greatest positive bias was generally found in November, but for the opposite reasons to that above. The temperature trend at this time

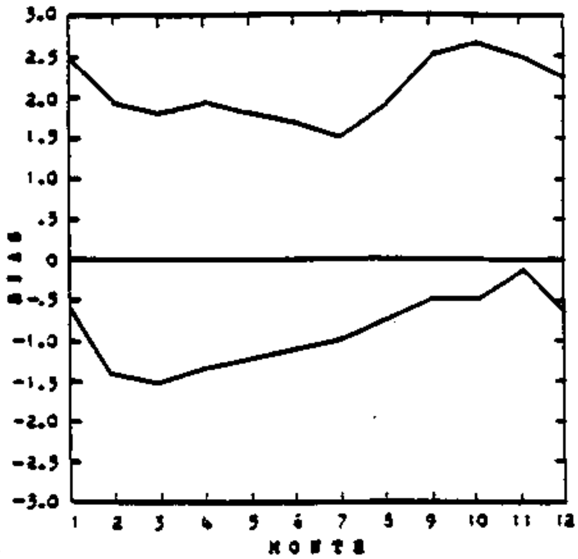


Fig. 5. Greatest positive and negative biases (°F) for each month at Bismarck.

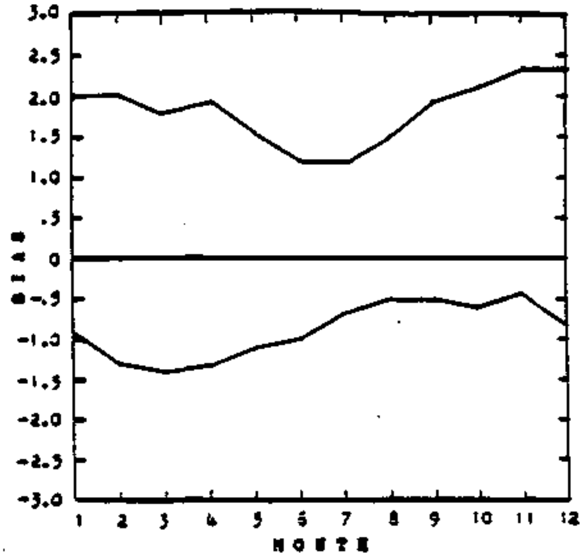


Fig. 6. Same as Fig. 5 for Des Moines.

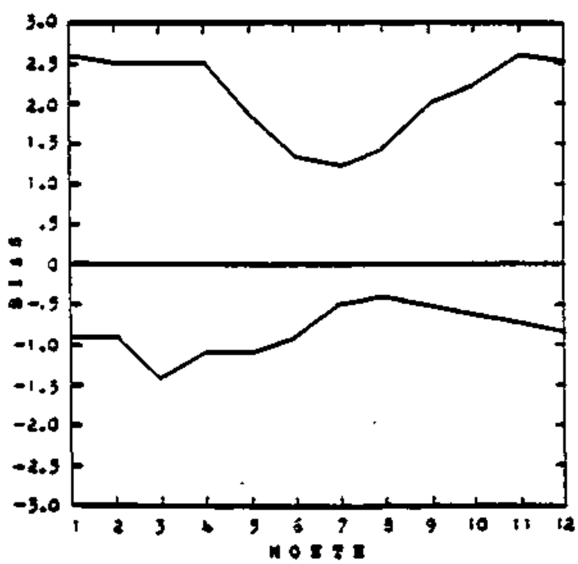


Fig. 7. Same as Fig. 5 for Dodge City.

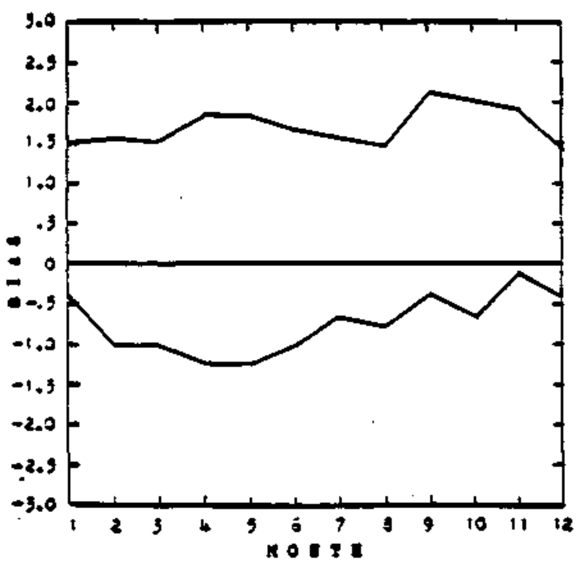


Fig. 8. Same as Fig. 5 for Flint.

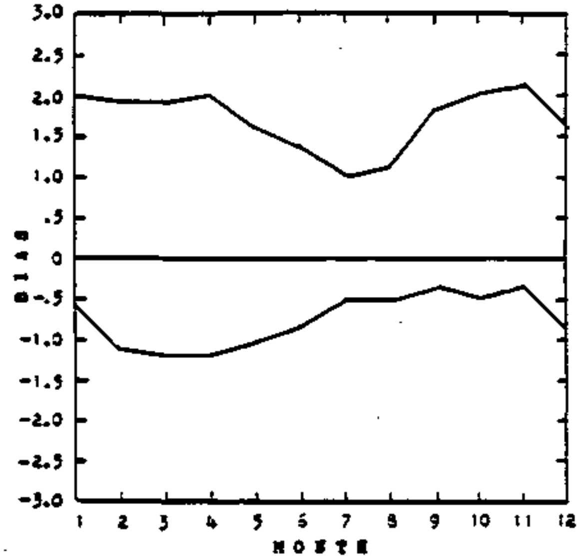


Fig. 9. Same as Fig. 5 for Indianapolis.

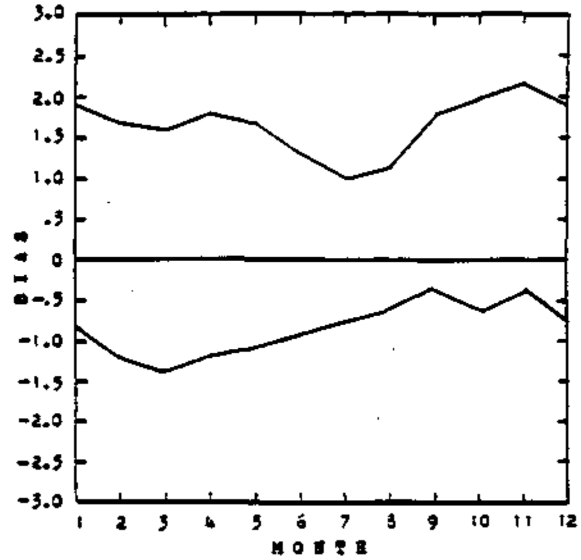


Fig. 10. Same as Fig. 5 for Peoria.

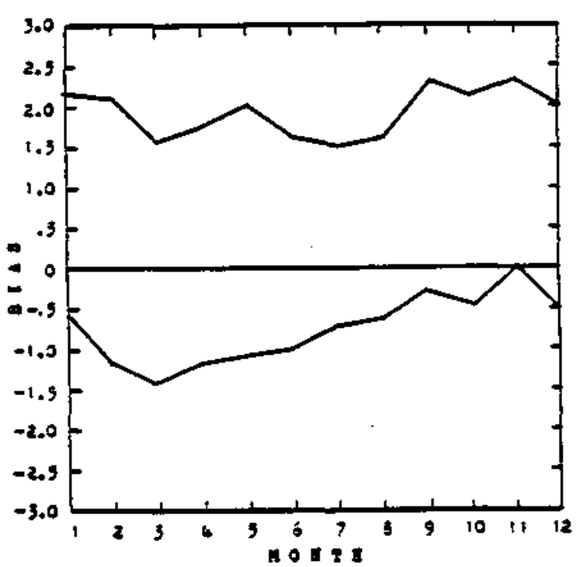


Fig. 11. Same as Fig. 5 for St. Cloud.

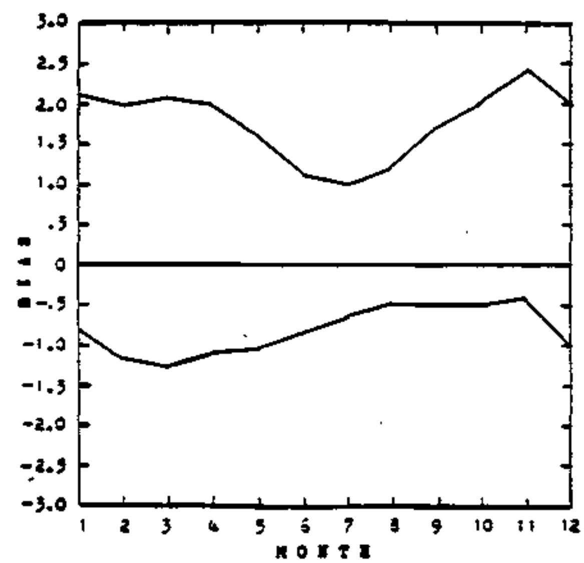


Fig. 12. Same as Fig. 5 for St. Louis.

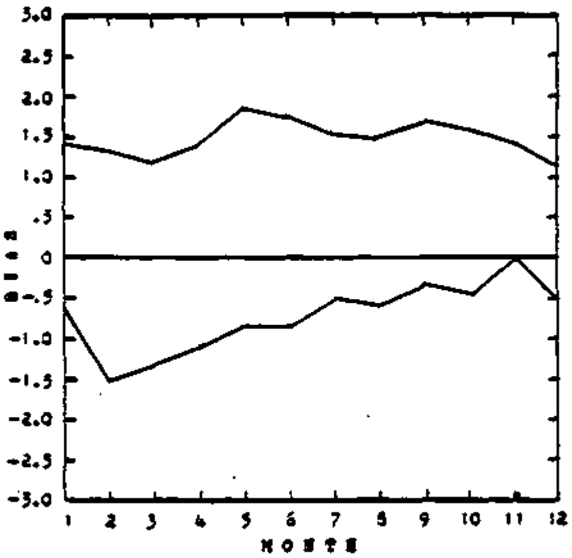


Fig. 13. Same as Fig. 5 for Sault Ste. Marie.

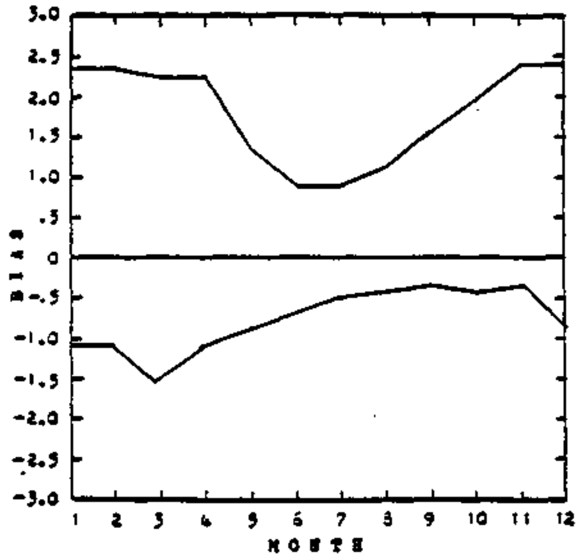


Fig. 14. Same as Fig. 5 for Springfield.

of year is decreasing at the maximum rate. Thus, the maximum temperatures near the beginning of the month are almost always higher than those near the end, adding maxima from the previous day more frequently into the next day's mean. Figures 5-14 will be discussed further in the next section.

The magnitudes of the greatest positive and negative biases of all months were added, giving the annual range of extreme biases for a particular station. When these ranges were compared, it was found that they were nearly 0.6 C (1.0 F) higher at the western stations than those located in the east (ranging from 2.3 C (4.2 F) at Bismarck to 1.8 C (3.3 F) at Flint and Indianapolis). Hence, a gradient (hereafter defined as the direction from highest to lowest values) in the ranges exists from west to east.

The author thought that since the annual range of extreme biases . expresses the greatest deviation for the year, perhaps a known unique climatic variable of location and temperature variability could be related to these biases. Continentality indices are generally proportional to a station's annual temperature range determined from mean monthly temperature data. A continentality index developed by Currey (1974) was computed for each station of this study and mapped for comparison along with the annual bias range. Values for each are shown in Figure 15 at each station with the index at the top and range of the extreme biases in the

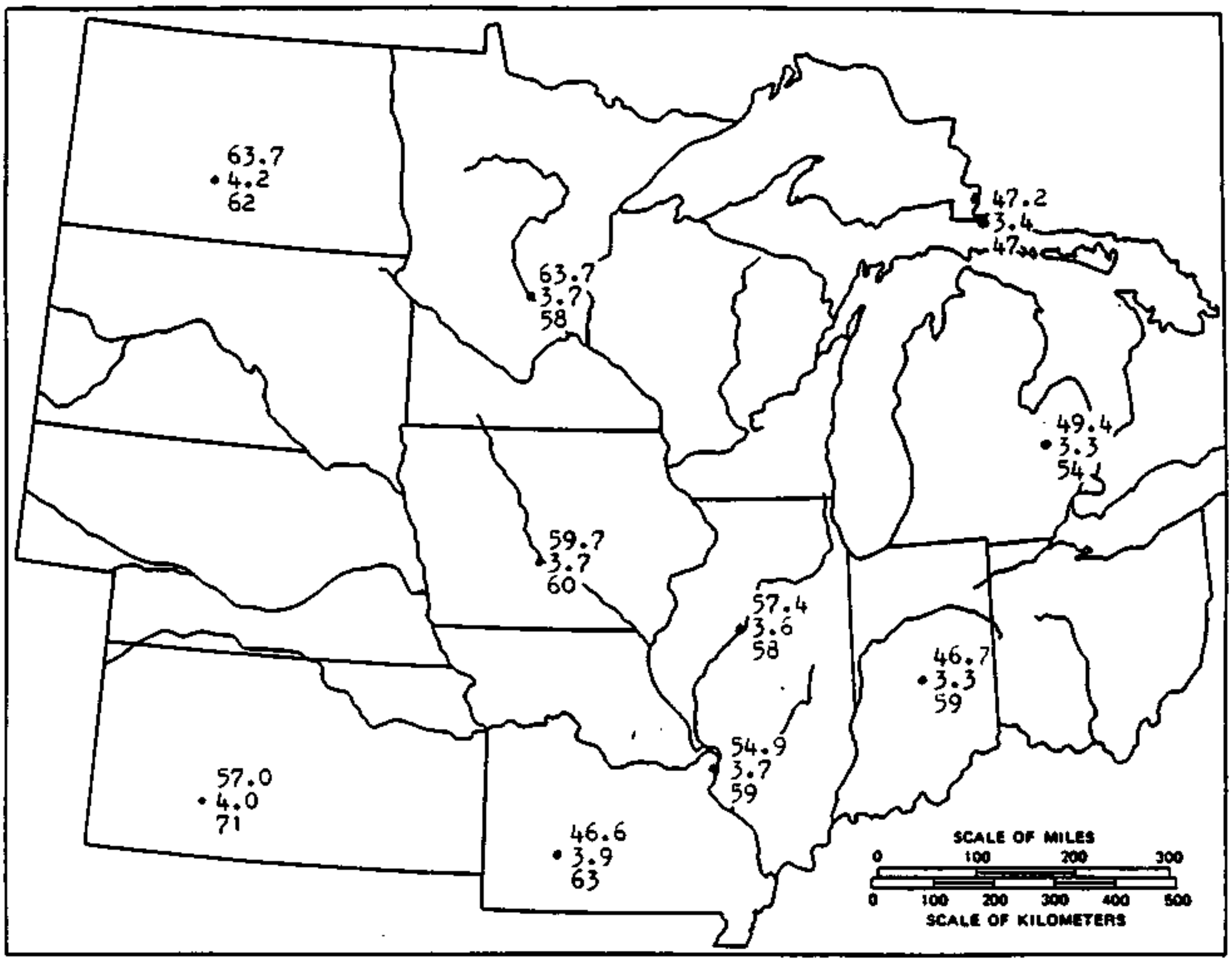


Fig. 15. Values of Currey's continentality index (top), the range of extreme biases (middle) in °F, and annual percent possible sunshine (bottom) are mapped for each station.

middle.

It was found that continentality increased from southeast to northwest in the study area. Thus, the lack of correspondence between the gradients due to the northern component in the indices suggested that an additional climatic variable was influential.

Annual percent possible sunshine, which is inversely related to mean cloudiness, was plotted for each station on the map in Figure 15 (lower value). These values increased distinctly from northeast to southwest. Thus it appears that the east- to-west increase in annual range of biases is a function of continentality (i.e., annual temperature range and latitude) and percent possible sunshine.

<u>Biases at Typical Hours</u>

Figures 16-25 show the biases at 0500, 0600, 0700, 1500, and 1900 hours during the months at each station. During the cooler months of the year (generally October through March), the biases at the three morning hours were virtually of the same magnitude. The small differences are due to the given hour's proximity to the time of sunrise (i.e., near the occurrence of the day's minimum temperature). In the warmer months, the differences between the biases at those hours increased markedly, with the 0500 hour generally exhibiting the greatest (negative) bias. The differences are also due to the nearness of the time of observation to sunrise. However, the greater differences

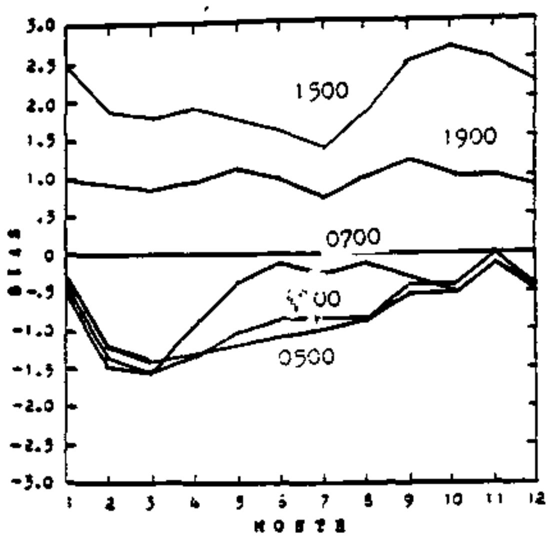


Fig. 16. Biases at 0500, 0600, 0700, 1500, and 1900 hours for all months at Bismarck.

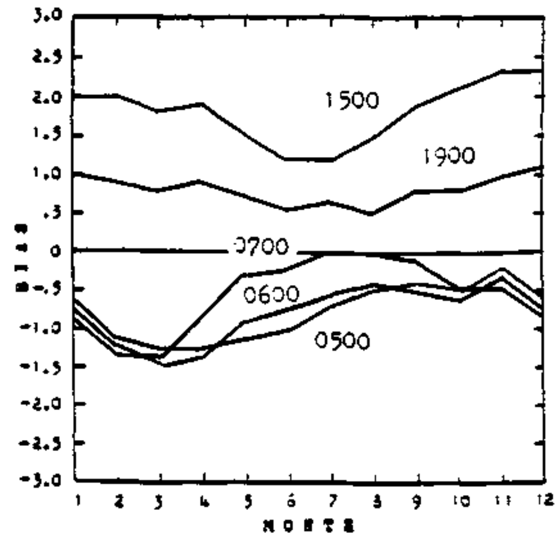


Fig. 17. Same as Fig. 16 at Des Moines.

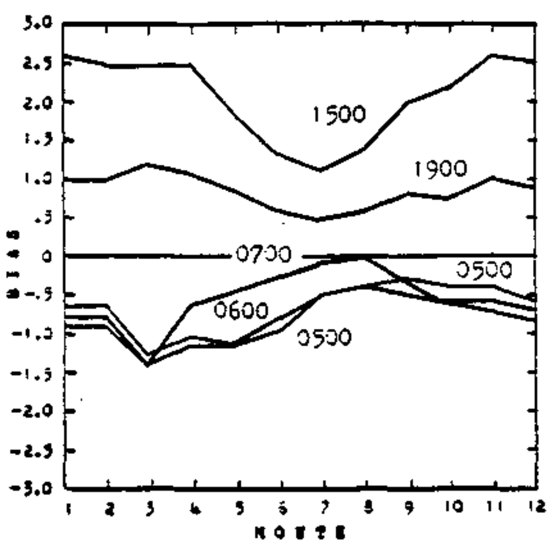


Fig. 18. Same as Fig. 16 at Dodge City.

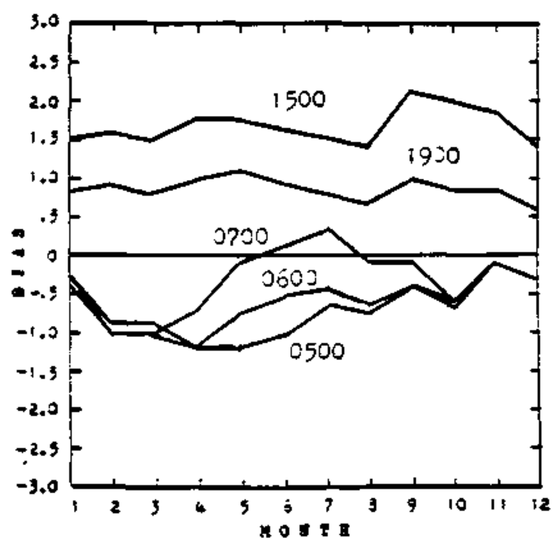


Fig. 19. Same as Fig. 16 at Flint.

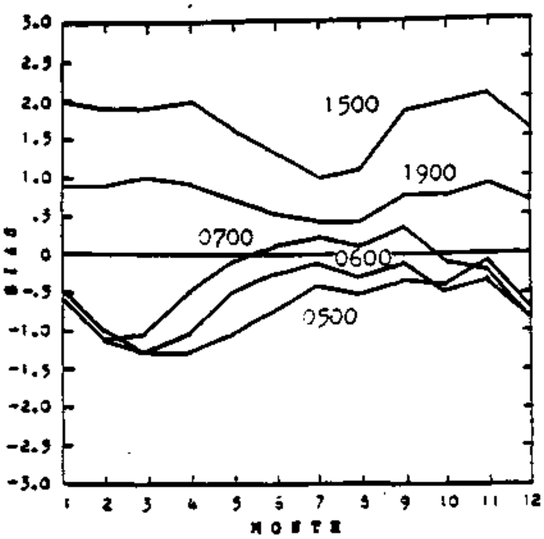


Fig. 20. Same as Fig. 16 at Indianapolis.

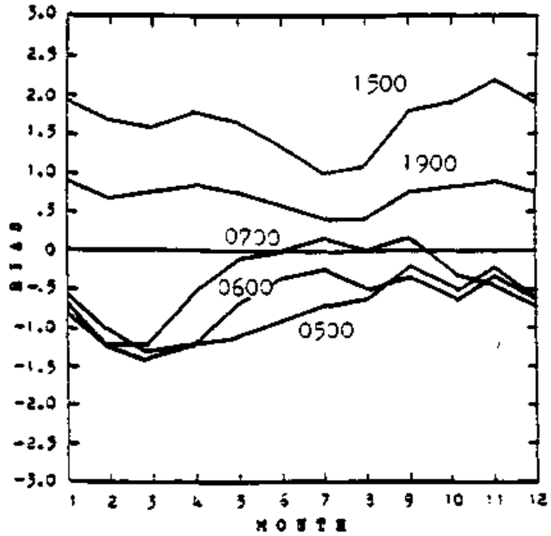


Fig. 21. Same as Fig. 16 at Peoria.

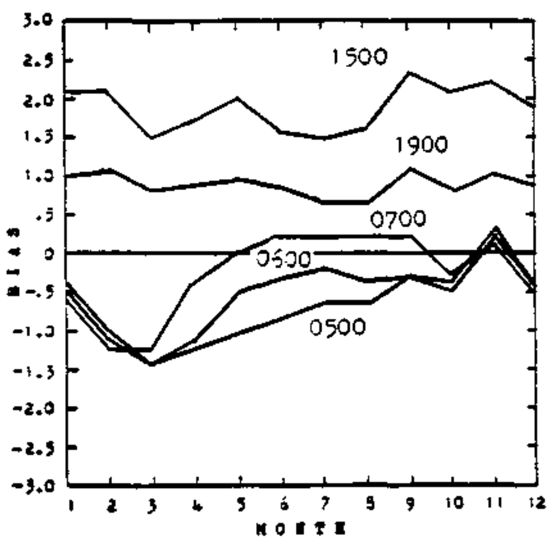


Fig. 22. Same as Fig. 16 at St. Cloud.

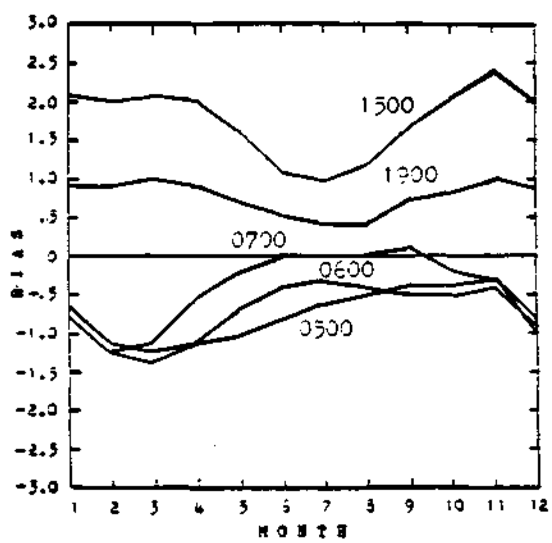


Fig. 23. Same as Fig. 16 at St. Louis.

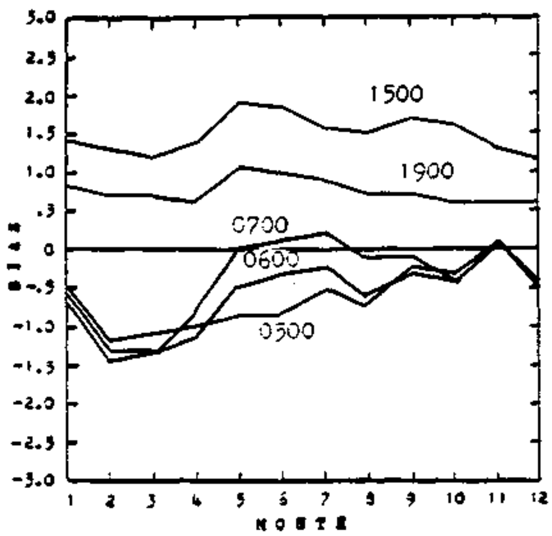


Fig. 24. Same as Fig. 16 at Sault Ste. Marie.

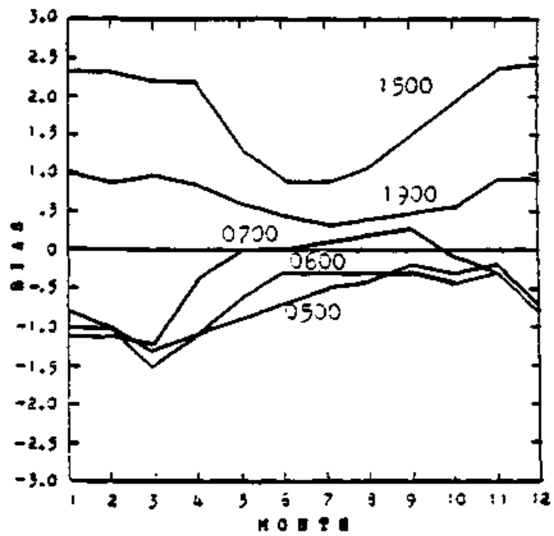


Fig. 25. Same as Fig. 16 at Springfield.

are due to 0500 hours being the approximate time of daily minimum temperature occurrence in these months, with the temperature thereafter rising rapidly toward the midnight-to- midnight mean temperature (i.e., the temperature around 0700 hours is equal or nearly equal to the day's mean). This can be seen in the curves of the hourly biases in Appendix A for the months April through September, where the bias at 0700 is zero or positive (e.g., Figs. A17 or A18).

The annual march of 1500-hour observations (shown in Figures 16-25) reflects the importance of the relationship between diurnal sun control (temperature response to solar forcing due to radiation), and frontal passage frequency on interdiurnal temperature change. This discussion applies to the greatest positive biases (Figures 5-14), since, as previously stated, these biases generally occurred at 1500 hours. In the lower-latitude stations (e.g., Dodge City, St. Louis), the pronounced minimum in the curves (smaller positive biases) centering on July is due to the relatively stable (although large in amplitude relative to winter) diurnal variation of temperature during the warmer months (i.e., maximum temperatures change little from day to day). The effect on the mean temperatures of the non-periodic variability introduced by extreme changes in temperature over a few hours from frontal passage is reduced, reaching a minimum in midsummer. Studies by Calef (1950), Sumner

(1953), Visher (1954), Landsberg (1966), and Crowe (1971) support this claim. The more northern stations' curves have a smaller or less well-defined minimum in the summer, thus the year-round effects of frequent frontal passage and cyclones in this region dampen the impact of diurnal sun control (Riehl, 1972; Trewartha and Horn, 1980). This is especially true at Sault Ste. Marie and Flint, where the frequency of cyclonic events is greater than at other stations of the study area. Reitan (1974) and Zishka and Smith (1980) show that the most frequent cyclone tracks for summer (July) follow a path across the northern states, converging around Sault Ste. Marie and Flint. The above observation is also true for the biases at 1900 hours: curves of less amplitude for the northern stations, and greater amplitude for the southern stations.

The curves for biases at 0500 hours are similar to the curves of greatest negative biases through the months, since the largest biases tend to occur at these hours (although this varies with the time of sunrise). As seen in Figures 16-25 for 0500 hours (also 0600) or the greatest negative bias curves in Figures 5-14, an upward trend of decreasing negative bias generally exists from March to November. This is due to the annual temperature curve's shift from the decreasing positive slope (decreasing frequency of minimum carryover) during March through July to the annual curve's increasing negative slope (increasing carryover of maxima) from July to November. The effect of minima carryover (the tendency toward negative bias) from frontal passages, cyclones, dissipation of cloud cover, etc. on the 0500-hour mean is dampened by maximum carryover from July through January, reaching a minimum around the time of maximal decrease in the annual temperature curve, hence the existence of the peak in the negative bias curve around September or November, depending on the station.

Bias by latitude

Curves of the normalized (see Equation 3, page 25) greatest positive and negative biases are presented in Figures 26-35. Figures 26 and 27 show the average of all eleven stations' positive and negative bias curves. Both curves show the generalized properties previously described. However, a few other characteristics are noteworthy. A secondary minimum in March on the positive curve suggests the dampening influence of relatively more frequent previous-day minimum carryover in this month.

Figure 28 shows the average curves of the greatest positive biases for the three different sets of stations by latitude group. They were grouped as follows: (high) Bismarck, Rapid City, St. Cloud, and Sault Ste. Marie; (mid) - Des Moines, Peoria, Flint, and Indianapolis; and (low) - Dodge City, Springfield, and St. Louis. The change from a relatively flat slope to a pronounced minimum (increased minimum temperature carryover) from low- to

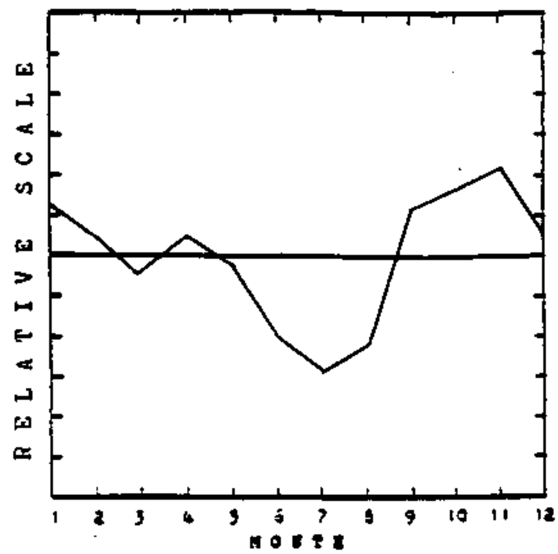


Fig. 26. Average of the 10 stations' normalized greatest positive biases for all months.

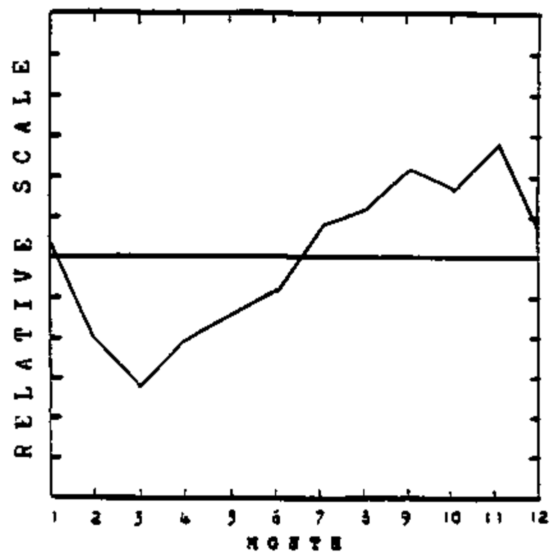


Fig. 27. Average of the 10 stations' normalized greatest negative biases for all months.

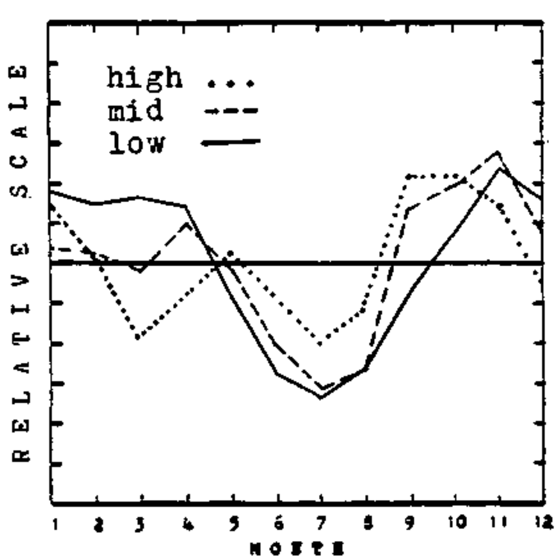


Fig. 28. Averages of the normalized greatest positive biases for the 3 different latitude groups for all months.

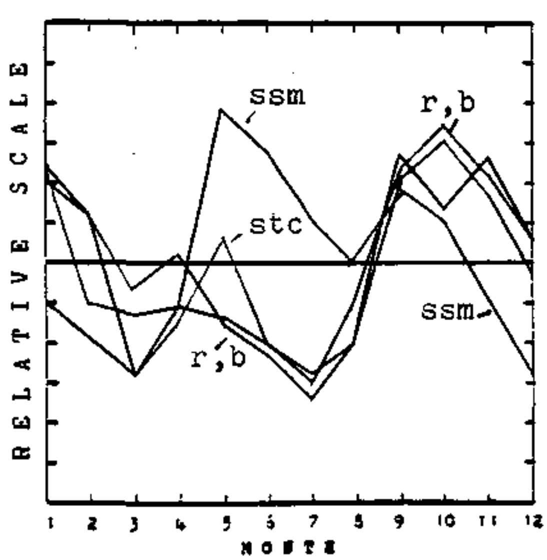


Fig. 29. Normalized greatest positive biases of all months for the stations of the 'high' latitude group.

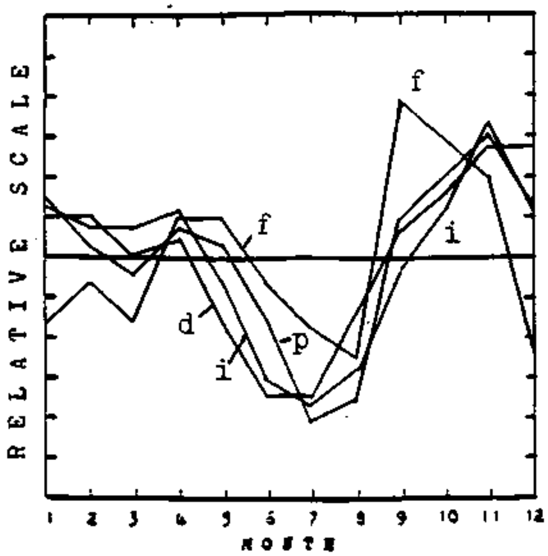


Fig. 30. Same as Fig. 29 for the 'mid' latitude group.

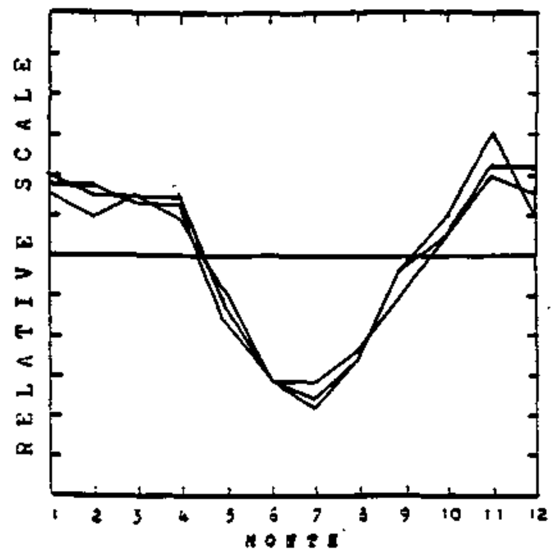


Fig. 31. Same as Fig. 29 for the 'low' latitude group.

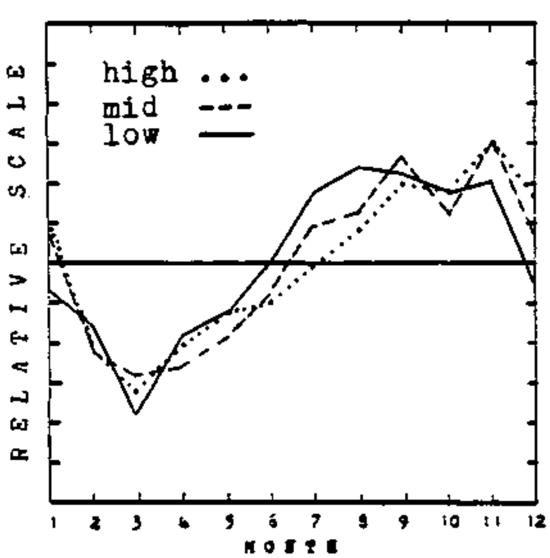


Fig. 32. Averages of the normalized greatest negative biases for the 3 different latitude groups for all months.

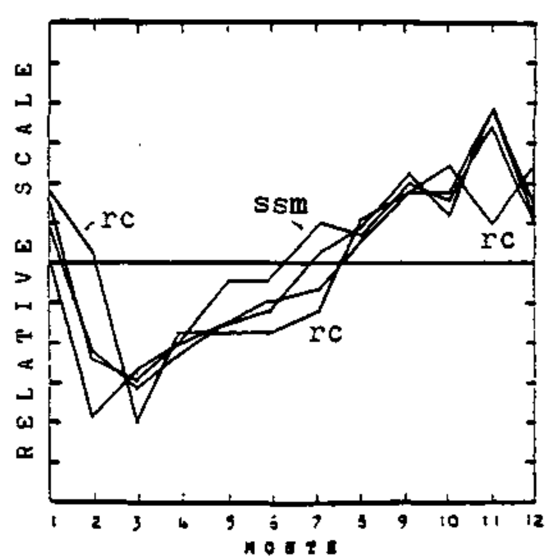


Fig. 33. Normalized greatest negative biases of all months for the stations of the 'high' latitude group.

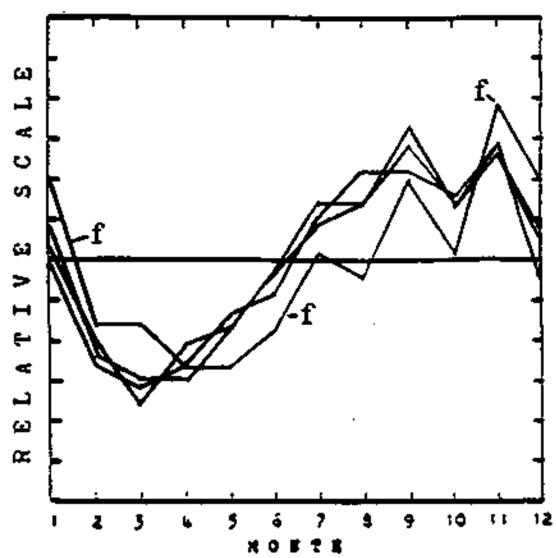


Fig. 34. Same as Fig. 33 for the 'mid' latitude group.

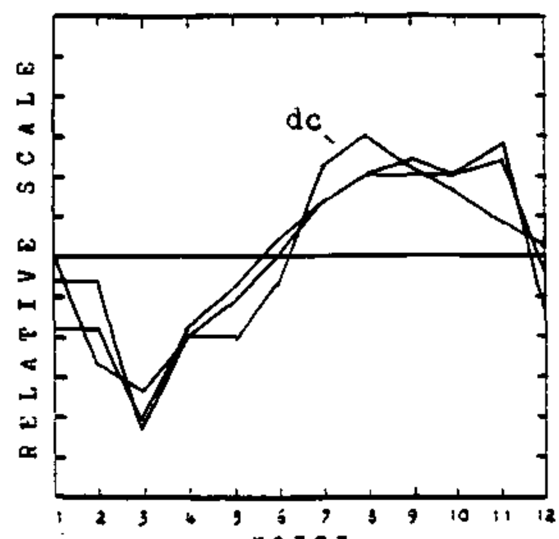


Fig. 35. Same as Fig. 33 for the 'low' latitude group.

high-latitude stations is most clearly noticed in March. The minimum centered on July is less pronounced when moving northward. Peak positive bias values for the high-latitude stations tend to occur earlier than lower-latitude locations (specifically, September or October versus November), suggesting the greatest decrease in the annual temperature curve happened in these months at these stations.

Figures 29-31 show the individual normalized greatest positive bias curves for each station and latitude group. Although the shape of the curves are similar within each latitude group, the individual curves tend to cluster more tightly from the high to low latitudes, indicating discontinuity within the higher latitudes of local geography (i.e., large lakes, aspect, topography, etc.). Sault Ste. Marie stands out clearly from the high-latitude group, reflecting the influence of Lake Superior (delayed seasonal peaks and moderation of extreme temperatures). This station reached its maximum positive bias in May. Flint, in the mid-latitude group, peaked in September, two months before the other three stations of this group. These differences could be a function of cyclone frequency and cloudiness.

The average of all of the stations' normalized greatest negative bias curves (Fig. 27) clearly shows the "minimum" bias in March and "maximum" in November previously described. The generalized trends of 1) decreasing negative bias from March to November, and 2) increasing negative bias from November to March, are obvious. A secondary peak occurs in September.

The average negative bias curves (Fig. 32) for the three latitude groups shows a slightly more pronounced minimum in March moving southward. Again, this reflects the more frequent carryover of minimum temperatures occurring in this month. From May to August a south-to-north gradient is directed from high to low latitude. This is in part due to the noticeable shift of the least negative bias in November at the high-latitude stations to August for the low-latitude stations (Fig. 32). Normalized negative bias curves for each group are shown in Figures 33-35. Flint deviated slightly from the other mid-latitude stations, with the minimum bias occurring in April and May, thus delaying the rising trend toward the least negative bias in its curve. Of slight consequence in the low-latitude group (Fig. 35) is the shift in the maximum (least largest negative bias) from November at St. Louis to September at Dodge City. This indicated that the greatest negative slope in the annual temperature curve occurs later in the fall from west to east.

Effect of Location Within a Time Zone

One aspect of the time a particular bias occurs is the lag (positive or negative) from the hour at the principal meridian on which recording times are based. Table 3 lists the individual stations' longitudes, time zone meridian, and minutes of lag (principal minus station's meridian) of the local time from the meridional time. Differences between the time of occurrence of the greatest positive and negative biases, and mid-morning zero biases at 1) St. Louis and Dodge City, and 2) St. Cloud and Bismarck, were calculated (defined as the former minus the latter). These stations were chosen because both members of each pair are at similar latitudes and they were the only pairs with a sufficient lag between the two stations (> 30 minutes) in a single time zone (Central). The differences were calculated for each month for each of the three occurrences mentioned, so a total of 36 lags for 1) and 35 lags for 2) above, were determined. Only 35 were used in the latter case because no negative biases occurred for November at St. Cloud (see Appendix A, Fig. A23). As seen in Table 4, St. Louis exhibited no lag and St. Cloud exhibited a small lag, indicating that their respective local times nearly coincide with that of the principal meridian. However, Dodge City and Bismarck lag behind the principal meridian by about 45 minutes.

Eighteen of 36 lags for the first pair, and 25 of 35 lags for the second, were found to be equal to or less than -45 minutes. This means that the hourly bias curves for western stations in this time zone (Central) lag behind those in the east. These same comments apply to the section found on pages 39-45.

Table 3. Each station's longitude, time zone principal meridian, and minutes lag of local time from standard time (4 minutes per degree longitude).

Station	Longitude	Principal Meridian	Minutes Lag
Bismarck	100°	90°	- 40
Des Moines	93°	90°	- 12
Dodge City-	100°	90°	- 40
Flint	83°	75°	- 32
Indianapolis	86°	75°	- 44
Peoria	89°	90°	+ 4
St. Cloud	94°	90°	- 16
St. Louis	90°	90°	0
Sault Ste. Marie	84°	75°	- 36
Springfield	93°	90°	- 12

Table 4. The greatest negative and positive biases, and range of biases (absolute negative plus positive) in °F for 1, 2, 4, 8, and 10 years record lengths at Peoria are shown for the months January, April, July, and October.

	JANUARY					APRIL				
YEARS	1	2	4	8	10	1	2	4	8	10
Negative	-0.4	-0.2	-0.8	-1.0	-0.8	-0.8	-1.2	-1.1	-1.2	-1.2
Positive	1.6	2.9	1.8	1.7	1.9	0.8	1.8	1.4	1.8	1.8
Range	2.0	3.1	2.6	2.7	2.7	1.6	3.0	2.5	3.0	3.0

	JULY					OCTOBER				
YEARS	1	2	4	8	10	1	2	4	8	10
Negative	-0.5	-0.9	-0.6	-0.6	-0.7	-0.8	-0.5	-0.6	-0.6	-0.6
Positive	1.0	1.2	1.0	1.0	1.0	1.7	2.3	1.7	1.9	2.0
Range	1.5	2.1	1.6	1.6	1.7	2.5	2.8	2.3	2.5	2.6

Three pairs of stations were assembled to determine at what hour the greatest positive bias occurred between stations within a pair. The following pairs were used: 1) Bismarck and Sault Ste. Marie, 2) Des Moines and Flint, and 3) Dodge City and Indianapolis. Just as in the discussion above, the time of this bias at the western stations was subtracted from that of the eastern location. These pairs were chosen because each has a comparable time lag within their respective time zones (see Table 4), although Des Moines' and Flint's lags differ due to twenty minutes. Thus, any time differences due to longitude will be relatively free of time zone lag problems, reflecting east-west regional climatic heterogeneity only.

It was found that during the six warmest months of the year (April through September), 14 of the 18 possible occurrences of the greatest positive bias in all of the western stations lagged behind those of the eastern stations by one hour. Since higher levels of atmospheric moisture and turbidity occur in the eastern portion of the region in these months due to airmass dominance, less net radiation was available for sensibly heating the air and for a shorter period of time (Thornthwaite, 1948; Rosenberg, 1974; Trewartha and Horn, 1980). Thus, maximum temperatures, and hence the greatest positive biases, occurred relatively earlier in the eastern stations than in the west.

Effect of Length of Record on the Biases

Table 4 lists the greatest positive, negative, and range of the extreme biases (positive plus negative bias) for one-, two-, four-, eight-, and ten-year record lengths at Peoria. Obviously, if the record is lengthened, regardless of which year or years of data are added, the magnitude of the biases is expected to change. However, gradually the biases should stabilize around some value. These patterns can most readily be seen in Table 4 in the ranges of the extreme biases. One- through four-year record lengths showed great variation for every season. For example, the difference between the mean greatest positive bias in January for one year and two years of data was almost the same magnitude as the bias for the one-year record itself (0.7 C (1.3 F)). The biases tend to stabilize at eight years of data with no change greater than 0.1 C (0.2 F) between the ranges of eight and ten years of data. This was true at all stations. January biases generally varied the most from one length of record to the next, whereas July changed the least. This was expected since the winter months tend to exhibit the greatest interdiurnal variability, and July the least.

Mapped Patterns in the Biases

To show the spatial distribution of the biases at particular hours of the day and seasons of the year, six maps were selected from those generated as described on page

22. Maps of the greatest negative biases found (regardless of the time of occurrence) are shown in Figures 36-40 at each station for January, March, July, September, and November. These particular biases were chosen because the patterns would not be skewed by the effects of time zone lag as described earlier. Since the greatest negative bias occurs near the time of sunrise for a given month, the biases are only related to a given station's local (solar) time.

The particular months were selected as representative of those times during the year when these biases typically reached a maximum or minimum, or were in transition (see Figure 27). Figure 36 shows the negative biases decreased from north and east to the southern part of the region in January. The biases in July (Fig. 38) were lowest in the northwest and greatest in the south, southeast, northeast. Biases in March (the typical month of maximum negative bias, Fig. 38) decreased from east to west, being a transition from January's to July's direction of highest to lowest values. September (Fig. 39) showed only a slight decrease from east to west, whereas November showed a strong north and east to south slope with a difference of 0.4 C (0.8 F) between Dodge City and Sault Ste. Marie.

Biases at 1500 hours found at each station for the same months as above were selected. Since the greatest positive bias occurs at 1500 hours in the majority of months for all

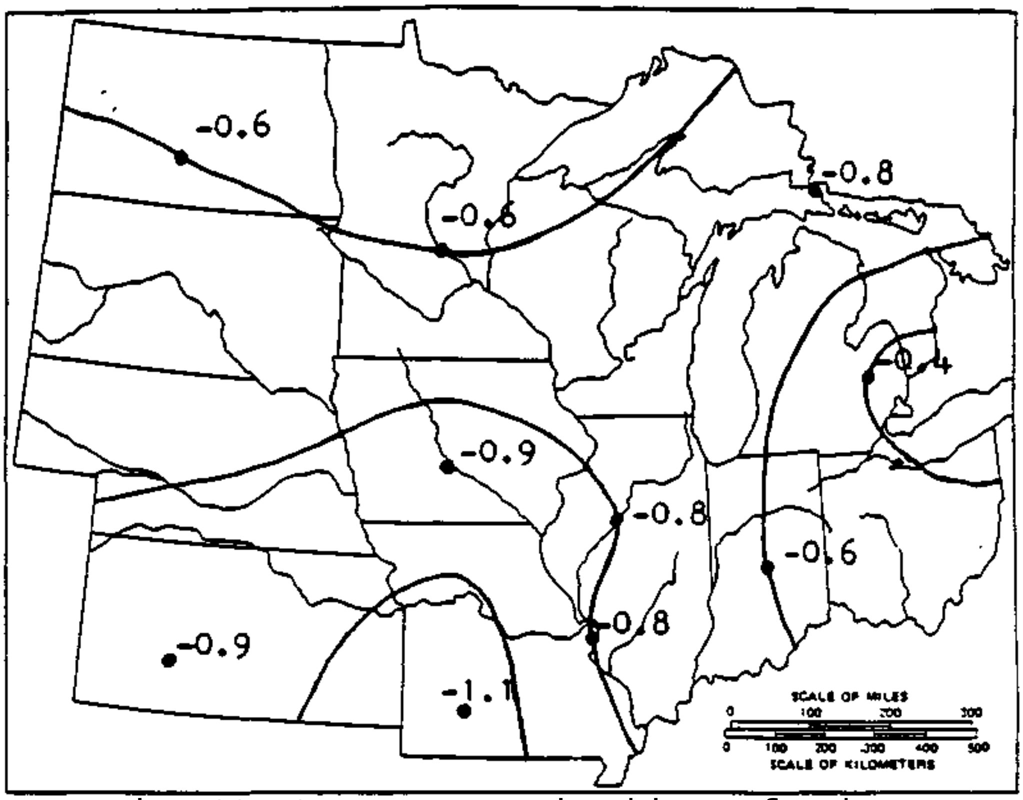


Fig. 36. Greatest negative biases found at each station during January without regard to the hour of occurrence. (˚F)

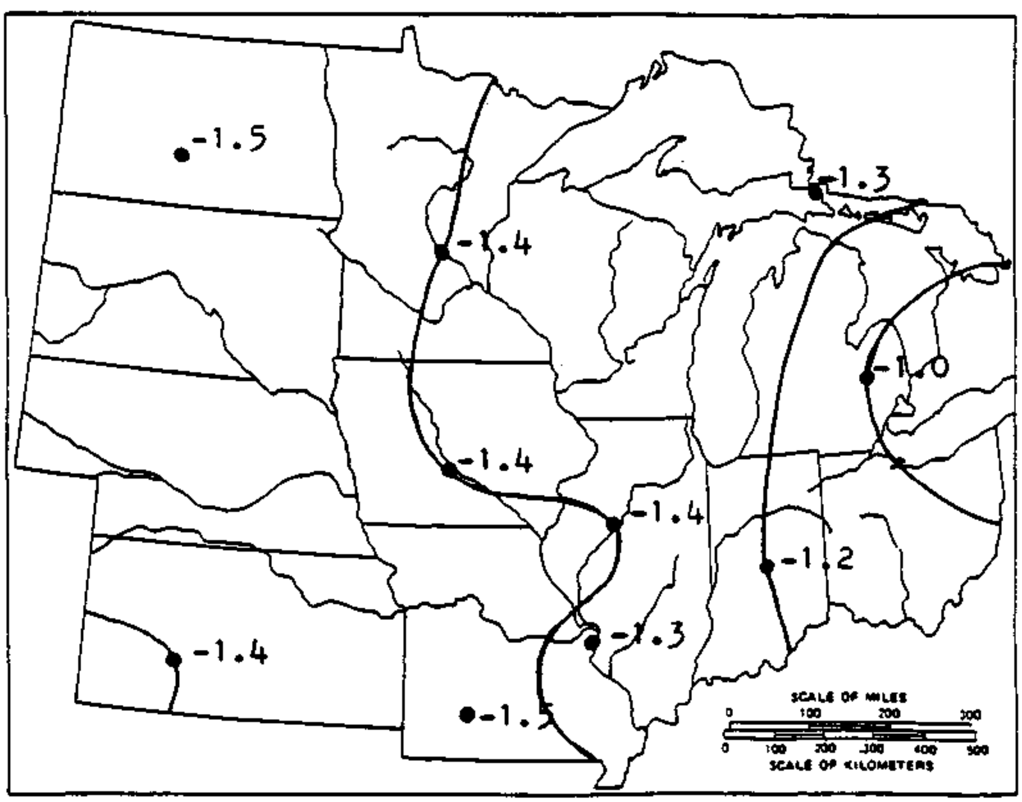


Fig. 37. Same as Fig. 36 for March.

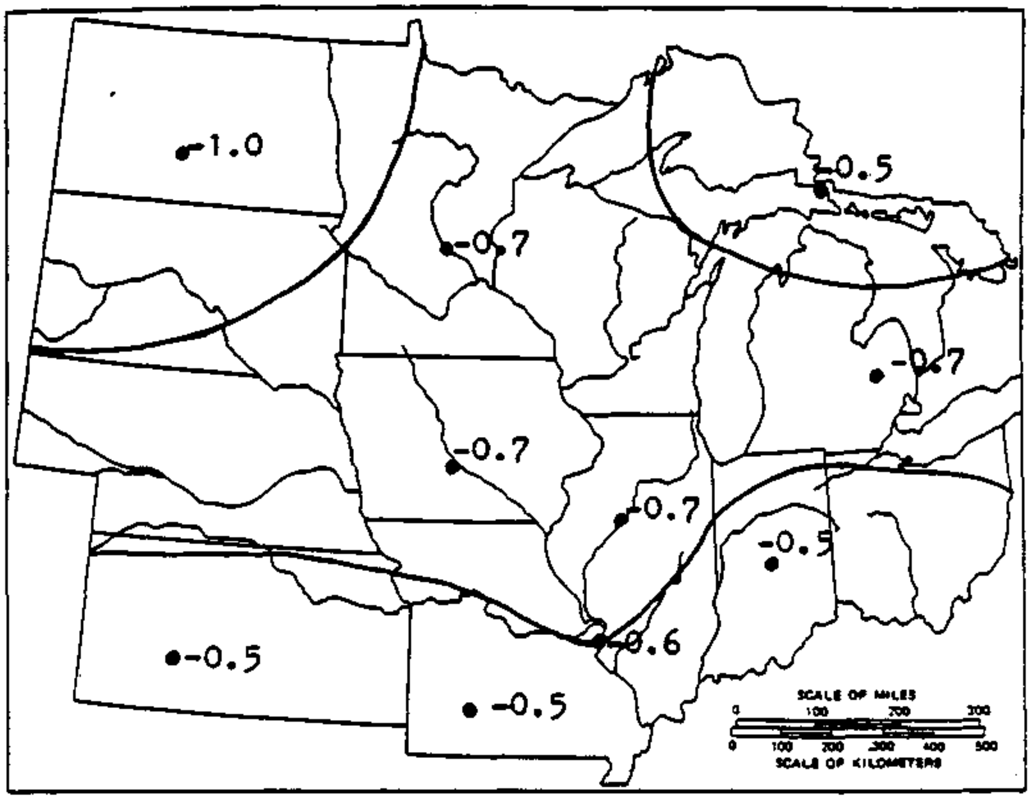


Fig. 38. Same as Fig. 36 for July.

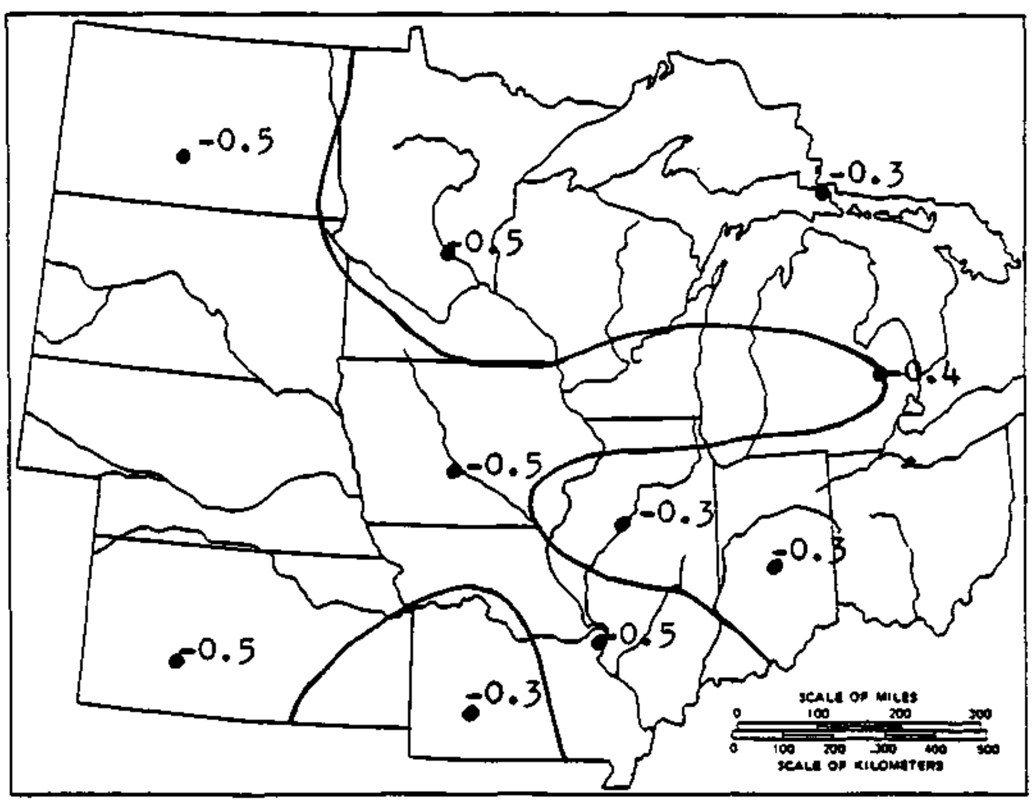


Fig. 39. Same as Fig. 36 for September.

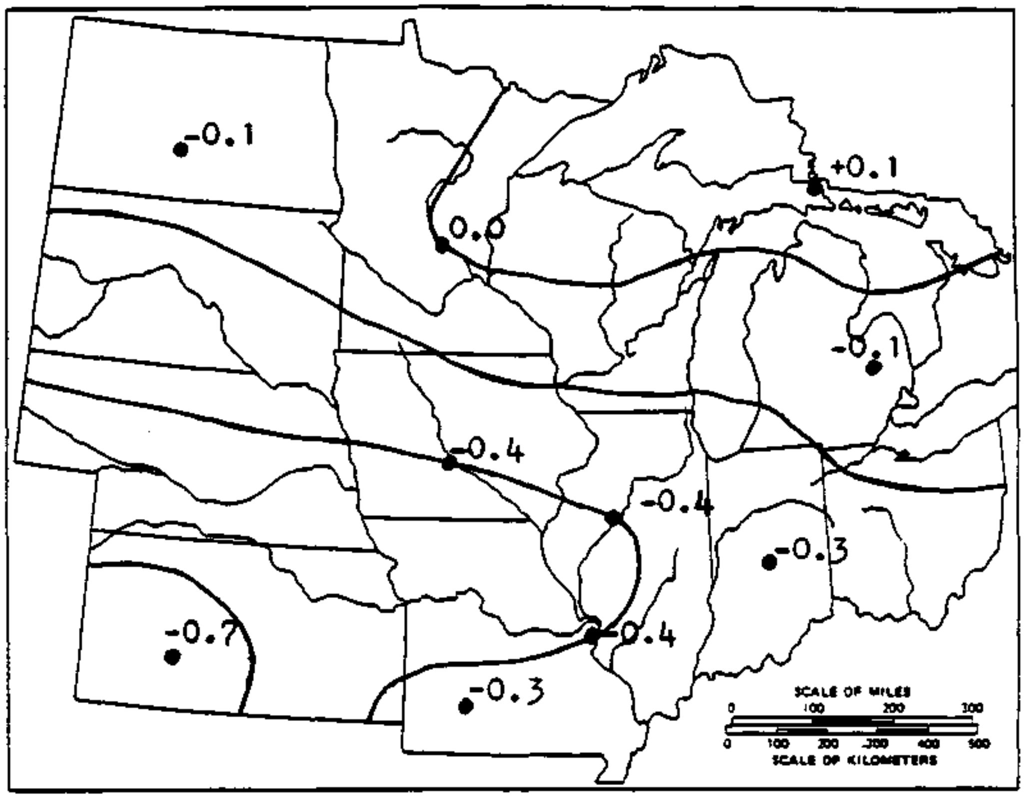


Fig. 40. Same as Fig. 36 for November.

stations, these maps represent the pattern in the greatest positive bias. Referring to Figure 26 will show a secondary minimum in March, a minimum in July, a secondary maximum in September, a maximum in November, and January as a transition month. Hence these months are shown in Figures 41-45. Although the 1500 LST biases could introduce the time zone lag problem into the mapped patterns, the difference between a particular station's biases at 1500 hours and 1400 or 1600 hours is typically less than 0.2 C (0.3 F).

The maps for 1500 hours in January and March (Figs. 41 and 42) show the gradient of high to low values directed from the west and south to the northeast. A dramatic change in direction occurred to this gradient in July (Fig. 43), with the biases decreasing from the northeast to the south and west in the opposite direction of the two previous months. An inspection of maps of other months (not shown) revealed that this large shift occurred between April and May. From July to November (Figs. 43-44), the gradient of decreasing biases rotated counterclockwise until the slope was similar in magnitude and direction to that of January (Fig. 41).

As noted earlier, the zero bias generally occurred at all stations around two hours after the maximum negative bias, or less than three hours after sunrise. Obviously, the time of sunrise for a particular month occurs at

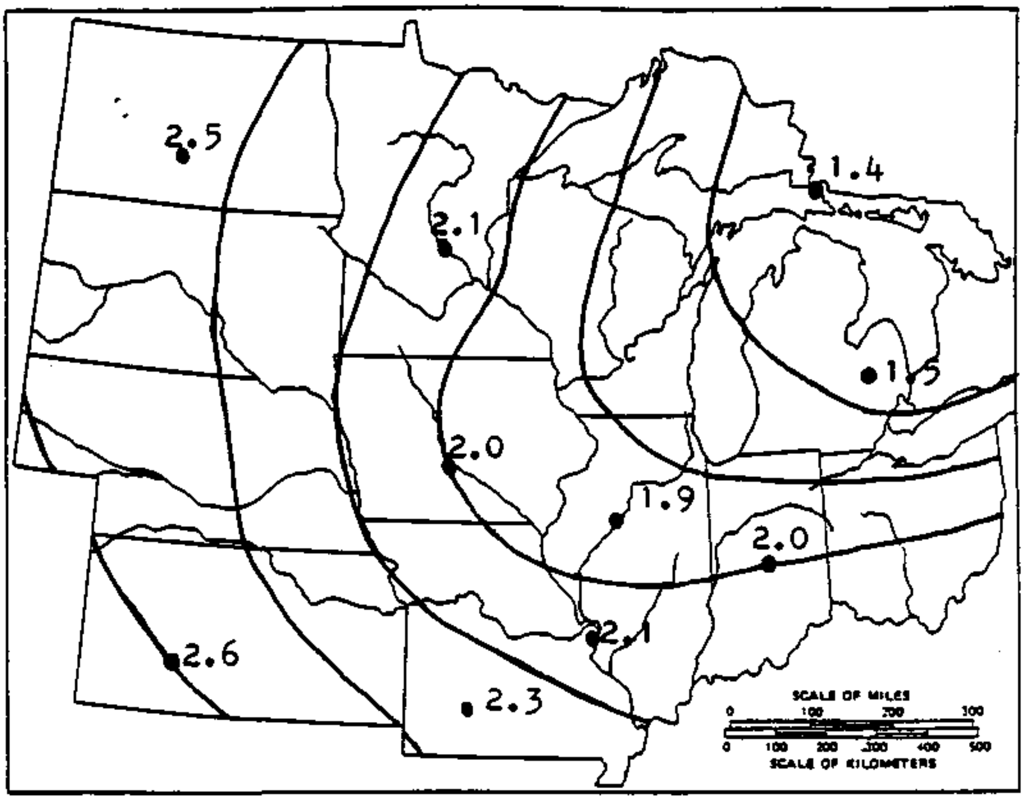


Fig. 41. The biases occurring at 1500 hours for each station during January. (˚F)

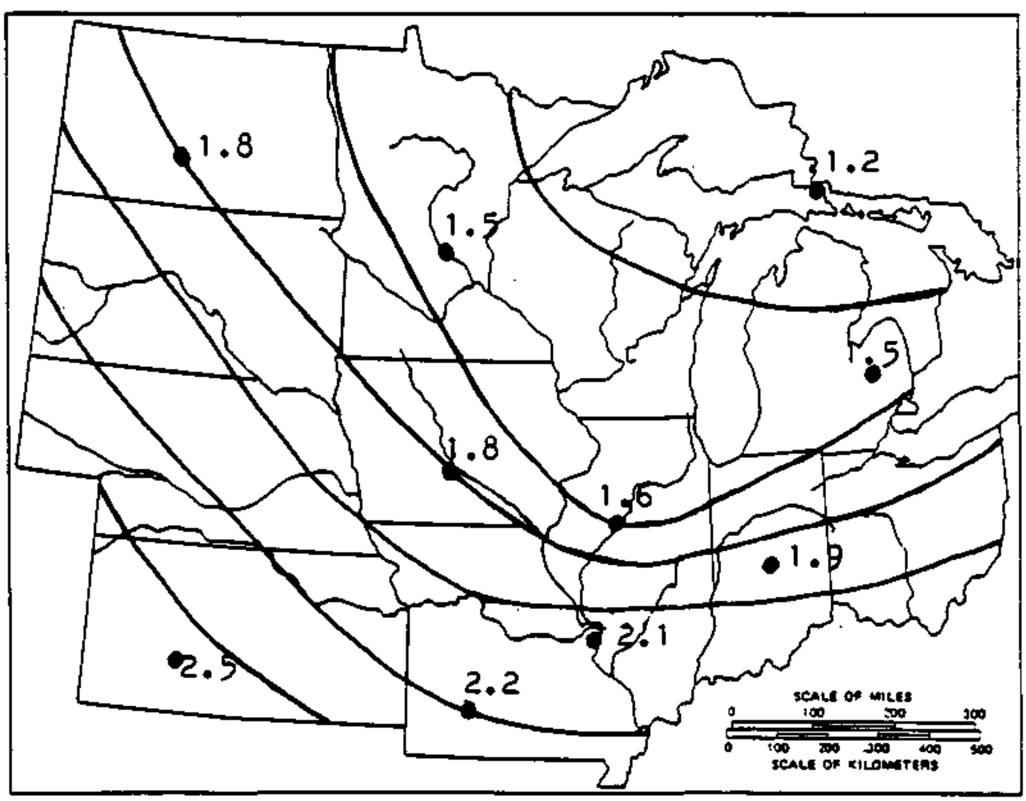


Fig. 42. Same as Fig. 41 for March.

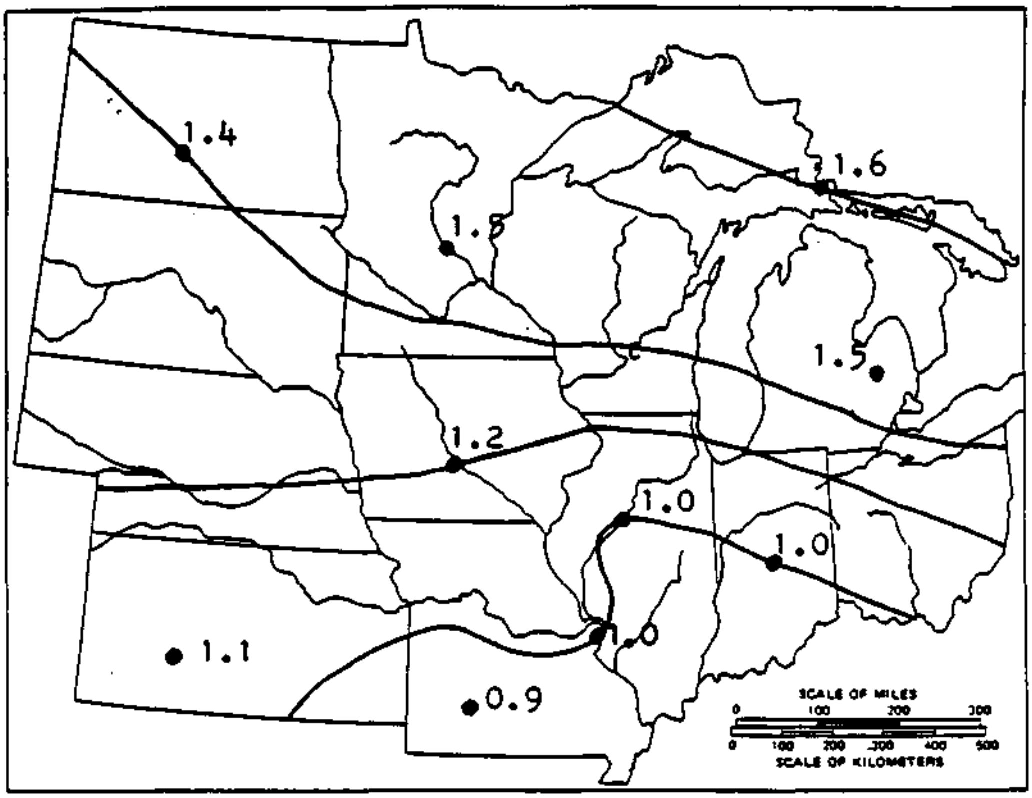


Fig. 43. Same as rig. 41 for July.

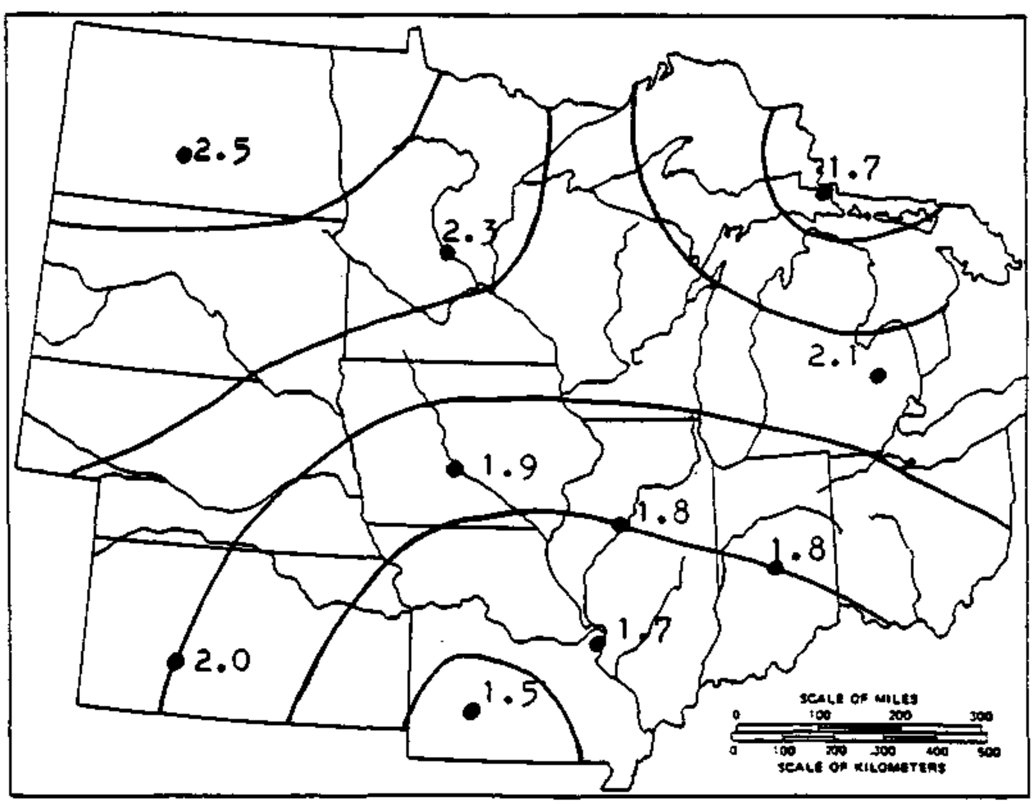


Fig. 44. Same as Fig. 41 for September.

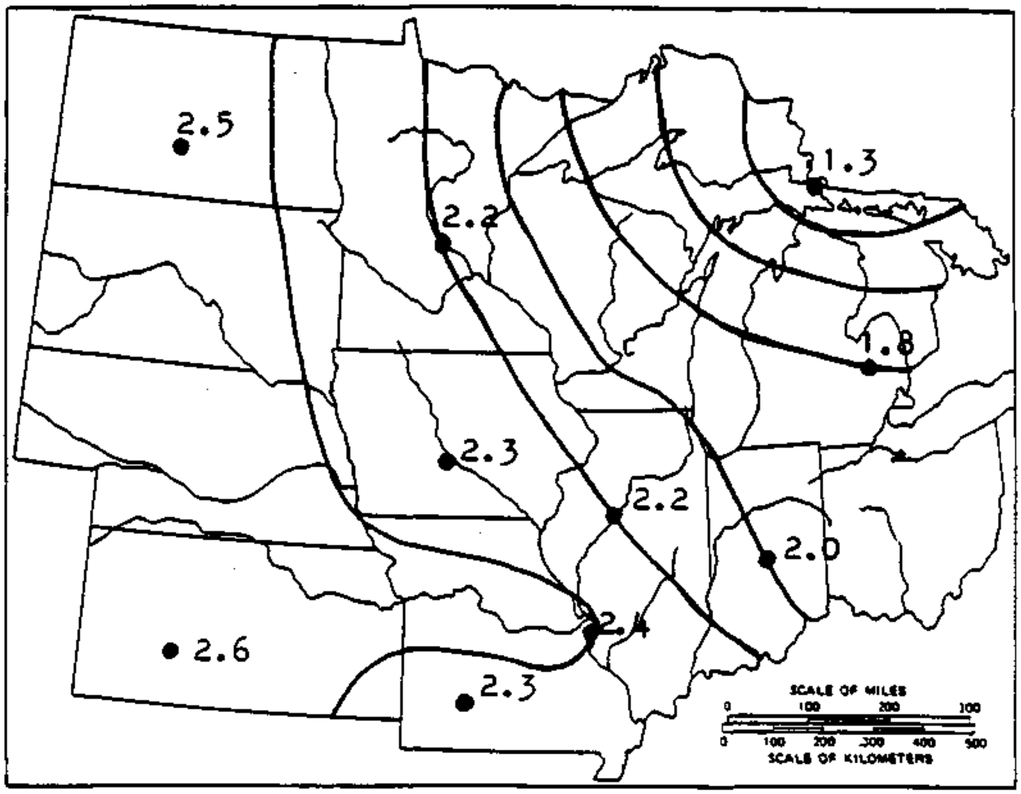


Fig. 45. Same as Fig. 41 for November.

different hours depending on latitude. Thus, the biases for 0900 in January, say, are not necessarily those that are nearest zero bias at a given station. This suggests that any mapped bias patterns from early morning to early afternoon (0100 to 1400 hours) should be interpreted cautiously, since the shape of the bias curves (Appendix A, Figures A1-A10) between these hours are controlled by the time of sunrise and the time zone lag problem.

To determine a bias for a station without data, interpolation is appropriate since the gradient of the bias field is generally on the order of only 0.1 C per 500 km.

CHAPTER 5

CONCLUSIONS AND FUTURE RESEARCH

The time of observation bias has been recognized by researchers since the late 1800s, although in past studies the systematic spatial variation of these biases was not fully explored. Also, correction factors for the biases from temperature records longer than, or equal to, ten years were not previously developed, and thus may have been unstable.

Biases varied as a function of at least the following seven variables from ten first-order National Weather Service stations in the Midwest and high plains: continentality, frontal passage frequency, latitude, length of temperature record, longitude, atmospheric moisture at the surface, and percent possible sunshine. Curves of the ten stations' greatest positive and negative biases found for each month fell into one of three latitude groups - 45 N (high), 41.5 N (mid), and 38 N (low). Differences of biases within a group were greatest in the high-latitude stations and lowest in the low-latitude stations. The range in the extreme biases (from 1.8 C (3.3 F) in the east to 2.3 C (4.2 F) in the west) at any given location increased with higher values of continentality.

Location of a station relative to its time zone principal meridian determined the time of occurrence of the biases. In general, western stations' biases negatively lagged behind those in the eastern part of a time zone by as much as sixty minutes. The later occurrence of the greatest positive biases at the western stations after the time zone lag had been corrected in the warmer half of the year is likely due to the longitudinal differences in atmospheric moisture, i.e., greater humidity and soil moisture in the east in the mean. No obvious systematic relationship was found between the biases and elevation. The elevation differences may not have been large enough to show a relationship.

The magnitudes of the biases (especially positive biases) were found to be in part controlled by the number of frontal passages at a station, more frequent in winter (e.g., a bias of 1.4 C (2.6 F) in January and 0.7 C (1.2 F) in July for Dodge City). Peak biases for all months occurred during the greatest change in the annual temperature curve, generally in March for negative biases (from -0.7 C (-1.2 F) in the southeast to -0.8 C (-1.5 F) in the north), and in September-November for positive biases (from 1.1 C (1.9 F) in the east to 1.5 C (2.7 F) in the west). The presence of more frequent cloud cover, which is inversely related to percent possible sunshine, dampened extreme biases. This effect decreased from northeast to southwest in the region.

The time of least bias (other than those hours near midnight) generally occurred between one and three hours after sunrise. Mean temperatures derived from readings once a day before the time of zero bias were generally lower than the 2400 mean (negative biases). Means from readings after the time of zero bias were higher than the midnight means (positive biases).

Biases varied by more than 0.1 C (0.2 F) between calculations from record lengths of less than eight to ten years. It was found that eight years of hourly temperatures is an adequate record length for deriving biases for use as corrections to non-midnight-to-midnight means.

The biases from the curves in Appendix A, Figures A1-A10 can be used as correction factors to any period means calculated from maximum-minimum temperatures read once a day at any consistent hour other than midnight. Since these corrections were calculated from record lengths of ten or more years, they are stable and suitable for correction application.

As an example of their use, those period means (normals) derived as above from a given hour, whose corresponding bias is negative, should be <u>increased</u> by the magnitude of the correction. This will adjust the mean temperature upward to the expected mean calculated from maximum-minimum temperature readings recorded at midnight during the same period. Positive biases or corrections are subtracted from their corresponding means.

The following findings were central to this study. For example, consider the biases to the means for a 1500 observation in the Des Moines area:

1) the bias ranges from 1.0 C (1.8 F) to 1.1 C (2.0 F) for January through April, so a correction centering on 1.1 C (1.9 F) is appropriate for these months;

2) the biases decreased for the next two months for a correction of 0.8 C (1.5 F) in May to a summer minimum correction in June and July of 0.7 C (1.2 F);

3) they then increase so the same corrections for May and April are applicable to August, 0.8 C (1.5 F), and September, 1.1 C (1.9 F), respectively;

4) October's correction of 1.2 C (2.1 F) is a transition to this observation's largest monthly correction in November and December, both 1.3 C (2.3 F). Therefore, corrections are similar in a) January, February, March, September, and October 1.0 - 1.2 C (1.8 - 2.1 F), b) May and August 0.8 C (1.5 F), c) June and July 0.7 C (1.2 F), and d) October and November 1.3 C (2.3 F). At this station a change in the observation time from 1500 to 0600 hours in April, say, would result in a decrease of 1.8 C (3.2 F) in the calculated mean temperature!

For the region, the spatial and temporal changes were found to be as follows:

1. Positive biases were greatest in the west and least in the east and northeast.

2. Negative biases were relatively uniform in magnitude across the region.

3. Positive biases were greatest in late fall and winter, and least in summer. This difference in magnitude between seasons was greatest in the south and least in the north. Sault Ste. Marie's and Flint's positive biases were greater in late spring and early fall, and least in winter.

4. Negative biases were found to be greatest in late winter, and least in the fall, with simple gradations in the negative biases at months between these seasons.

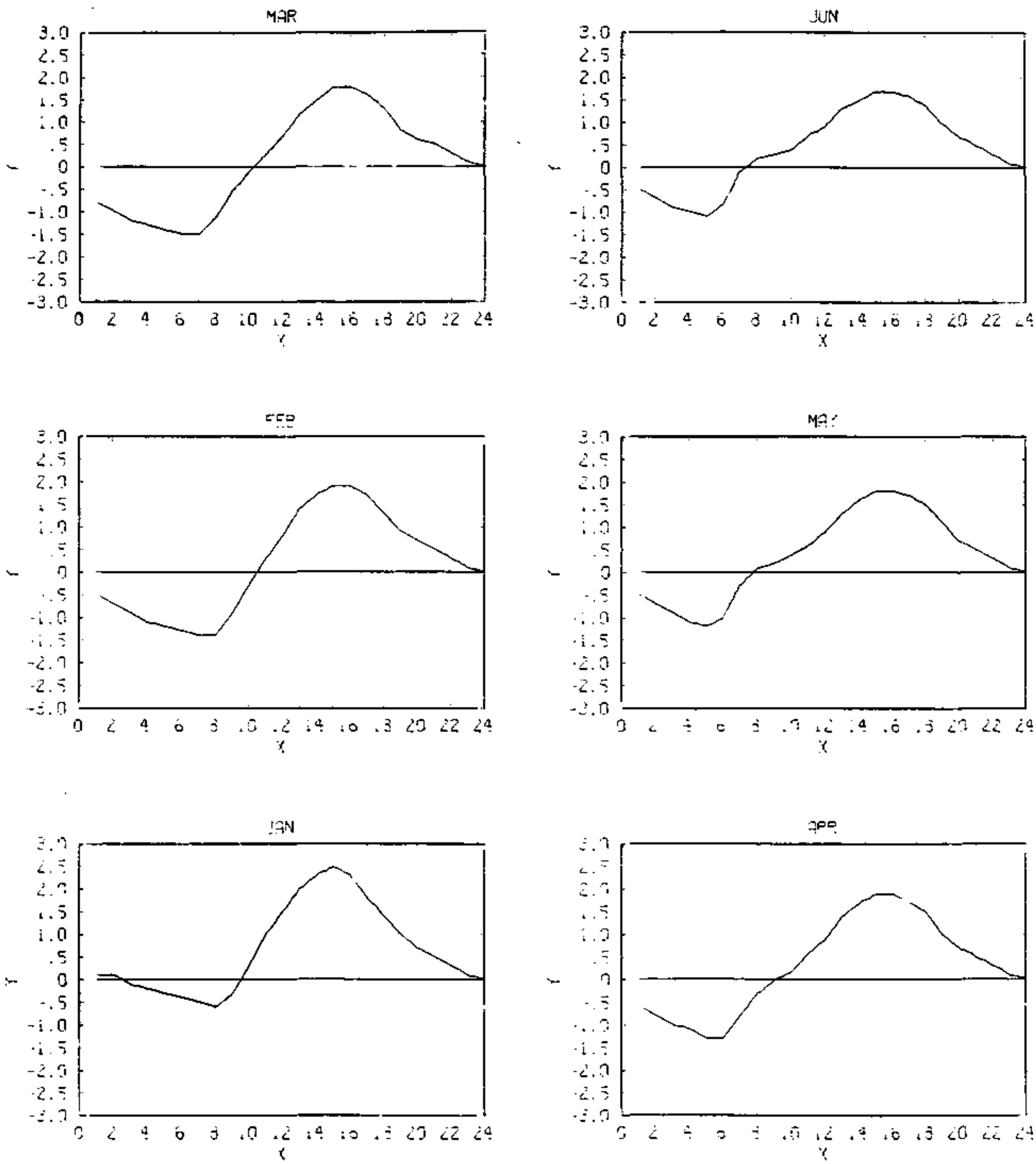
This study shows areas where similar corrections apply. For example, the three stations, Peoria, St. Louis, and Indianapolis, all exhibit a bias of 0.6 C (1.0 F) in July for a 1500-hour observation. Thus a station between these three stations would also experience a correction of 0.6 C (1.0 F).

Also, areas of corrections can be geographically interpolated. For example, in March, the corrections at 1500 hours are 1.2 C (2.2 F) at Springfield and St. Louis, 1.0 C (1.8 F) at Des Moines, 0.9 C (1.6 F) at Peoria, and 1.1 C (1.9 F) at Indianapolis (see Figure 42). Depending on roundoff, a correction of 1.0 C (1.8 F) or 1.1 C (1.9 F) could then be applied to stations midway between Peoria and St. Louis. This method can be applied to the weather stations throughout the region, thus eliminating the need for costly determination of biases from long time series (if they exist) at every cooperative and first-order station. However, influences such as bodies of water, aspect, local topography, etc. can modfiy the correction factors (biases) by an unknown amount at any given location. Therefore, caution must be used when interpolating between stations of very different local geography.

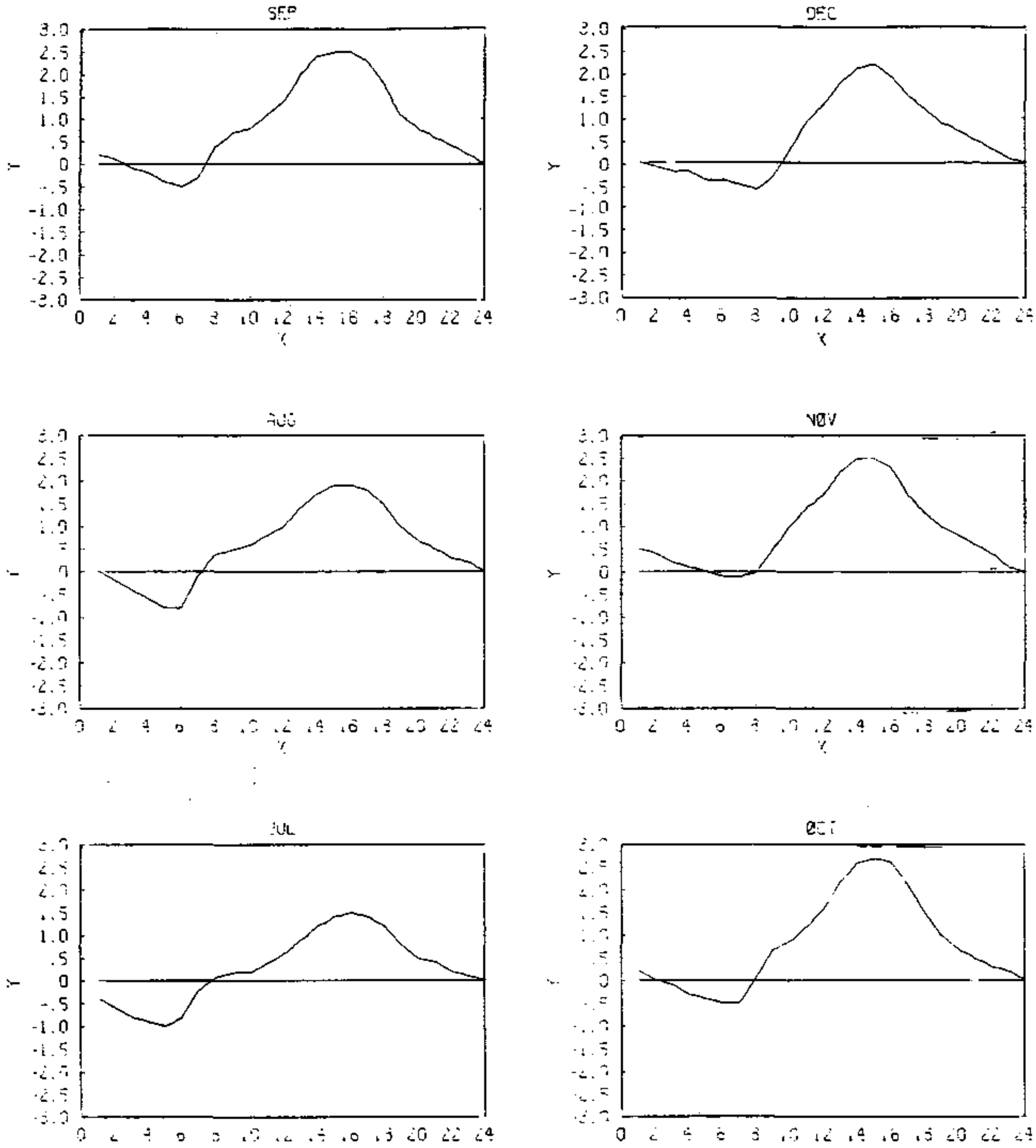
A future study should include correlating any number of the seven variables (except the effect of the length of record) in a multiple regression procedure to quantify the significance of the climatic and systematic relationships for modeling. Stations for the rest of the United States should be studied to determine the effects of extreme elevation, coastal and interior location, latitude and longitude differences, and extreme climatic regions (e.g., west coast location versus Gulf or east coast location) on the time of observation biases.

APPENDIX A

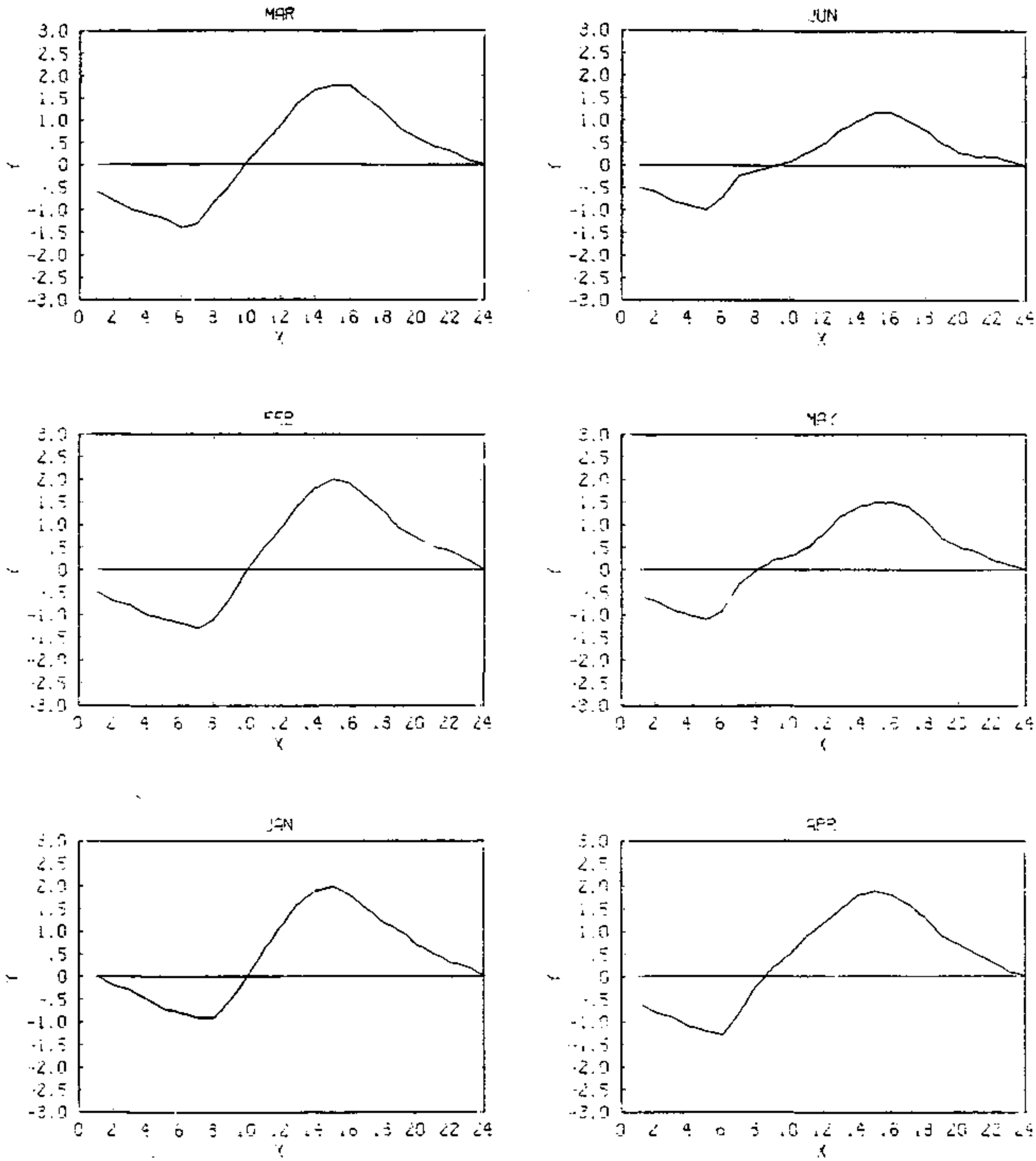
Figures A1-A20 show the 15-year (10-year for Peoria) mean biases in degrees Fahrenheit for each hour and month at the ten stations, i.e., the difference between the mean of the observations ending at a given hour and the midnight mean for that month. These figures may be used to convert norms for a best estimate of midnight-to-midnight means.



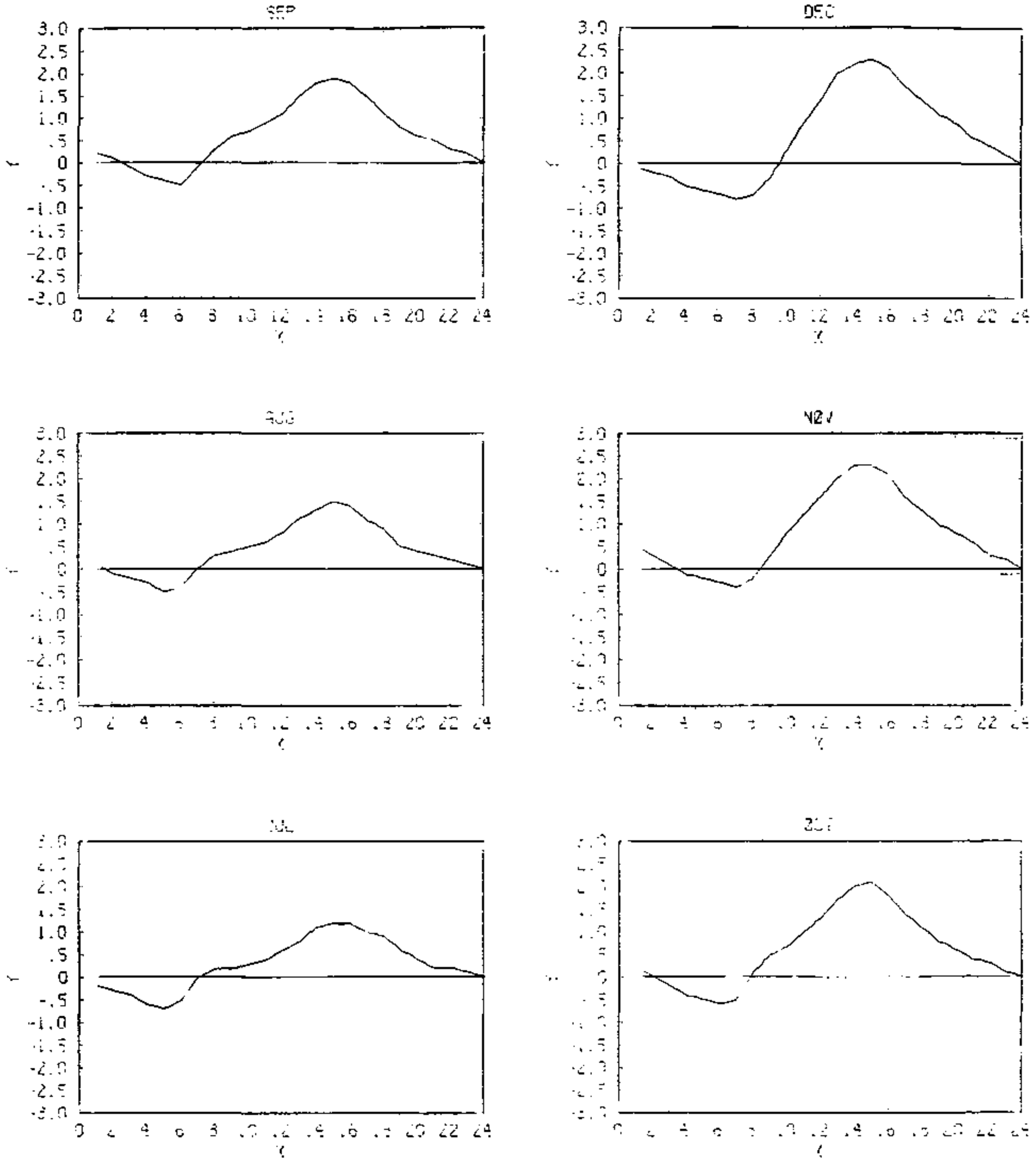
A 1. Bismarck


SEP
DEC
AUG
NOV
JUL
OCT
3.0
2.5
2.0
1.5
1.0
.5
0
-.5
-1.0
-1.5
-2.0
-2.5
-3.0
Y
0 2 4 6 8 10 12 14 16 18 20 22 24
X

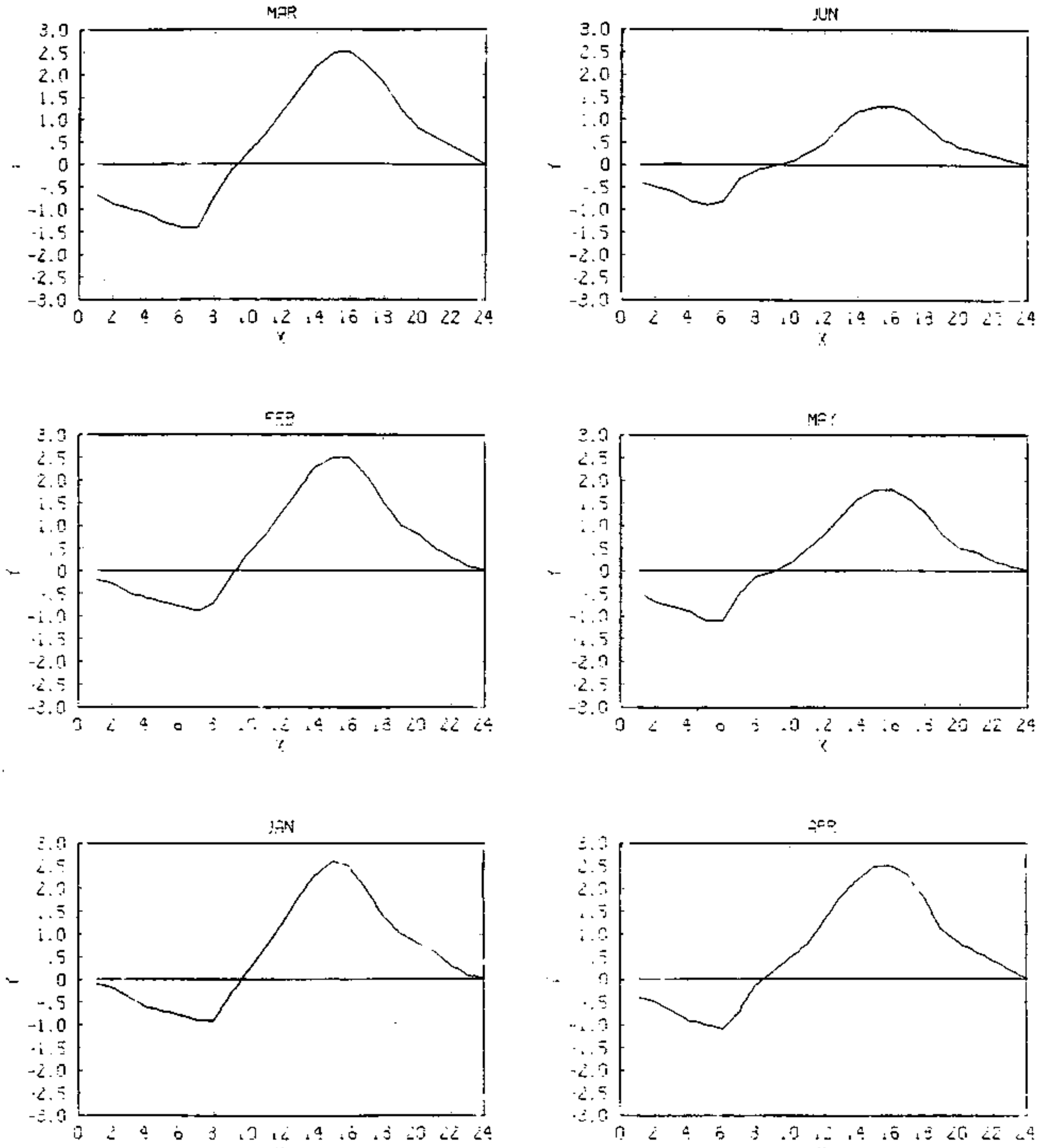
A 2. Bismarck



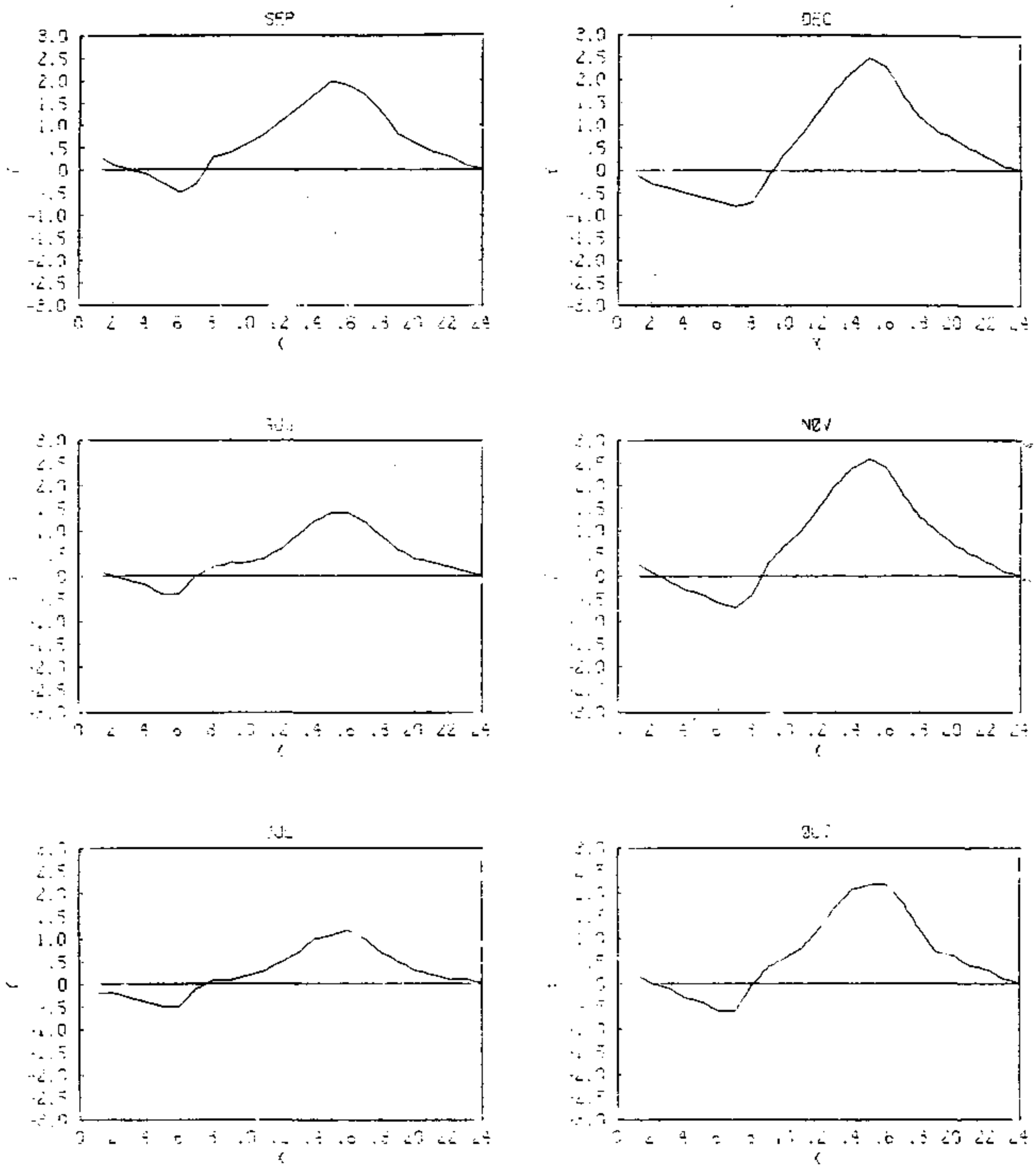
A. 3. Des Moines



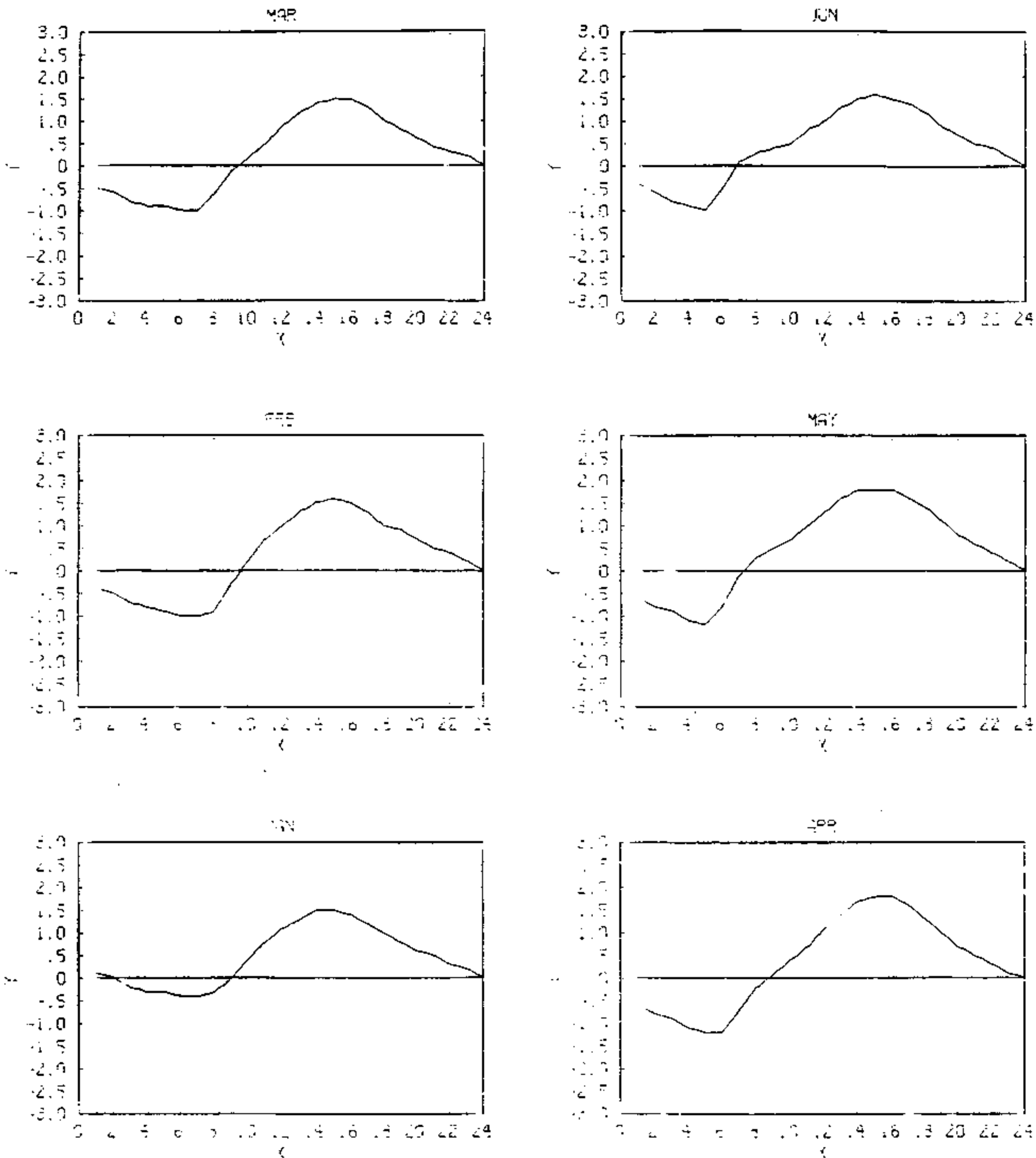
A 4. Des Moines



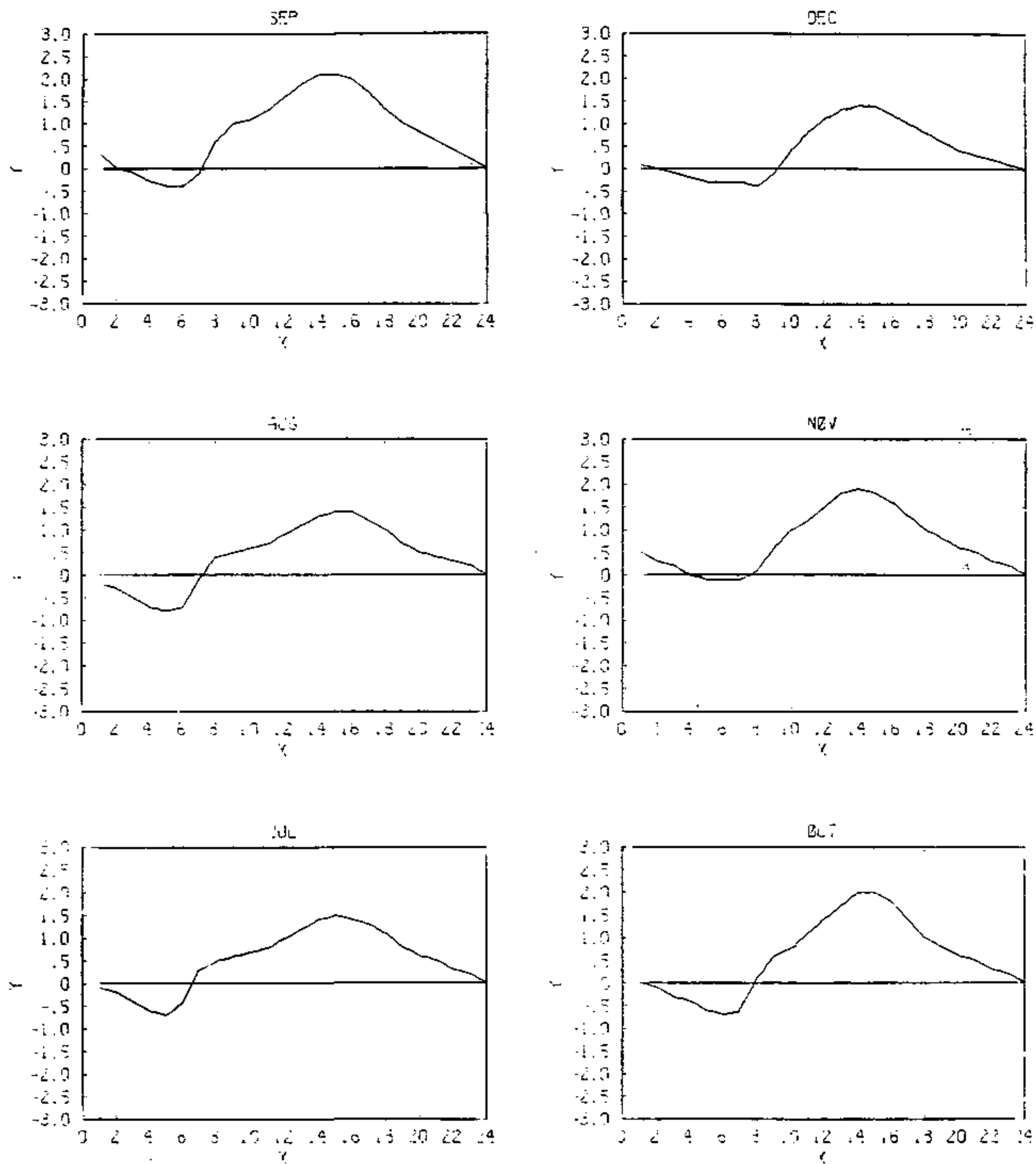
A 5. Dodge City



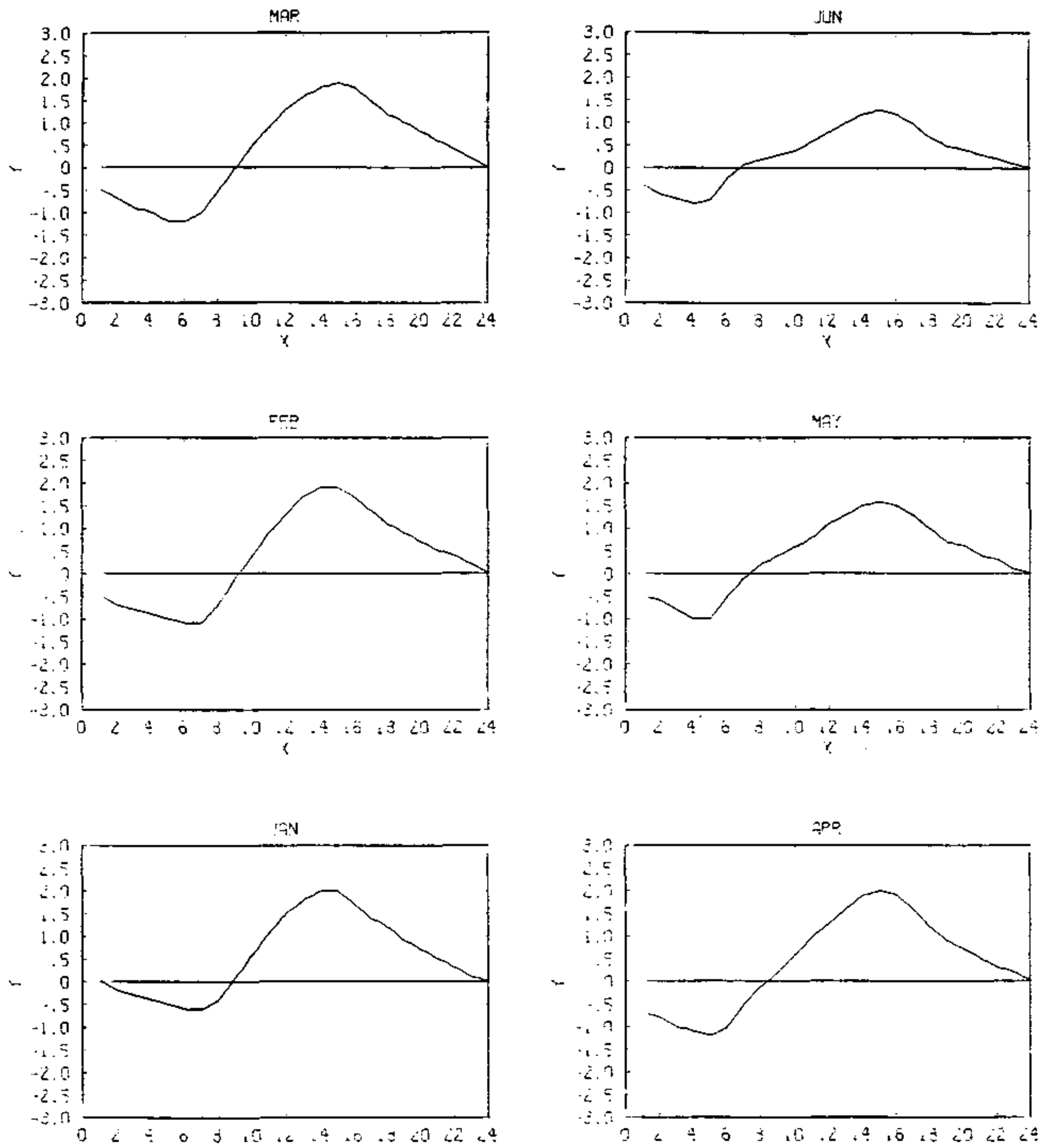
A 6. Dodge City



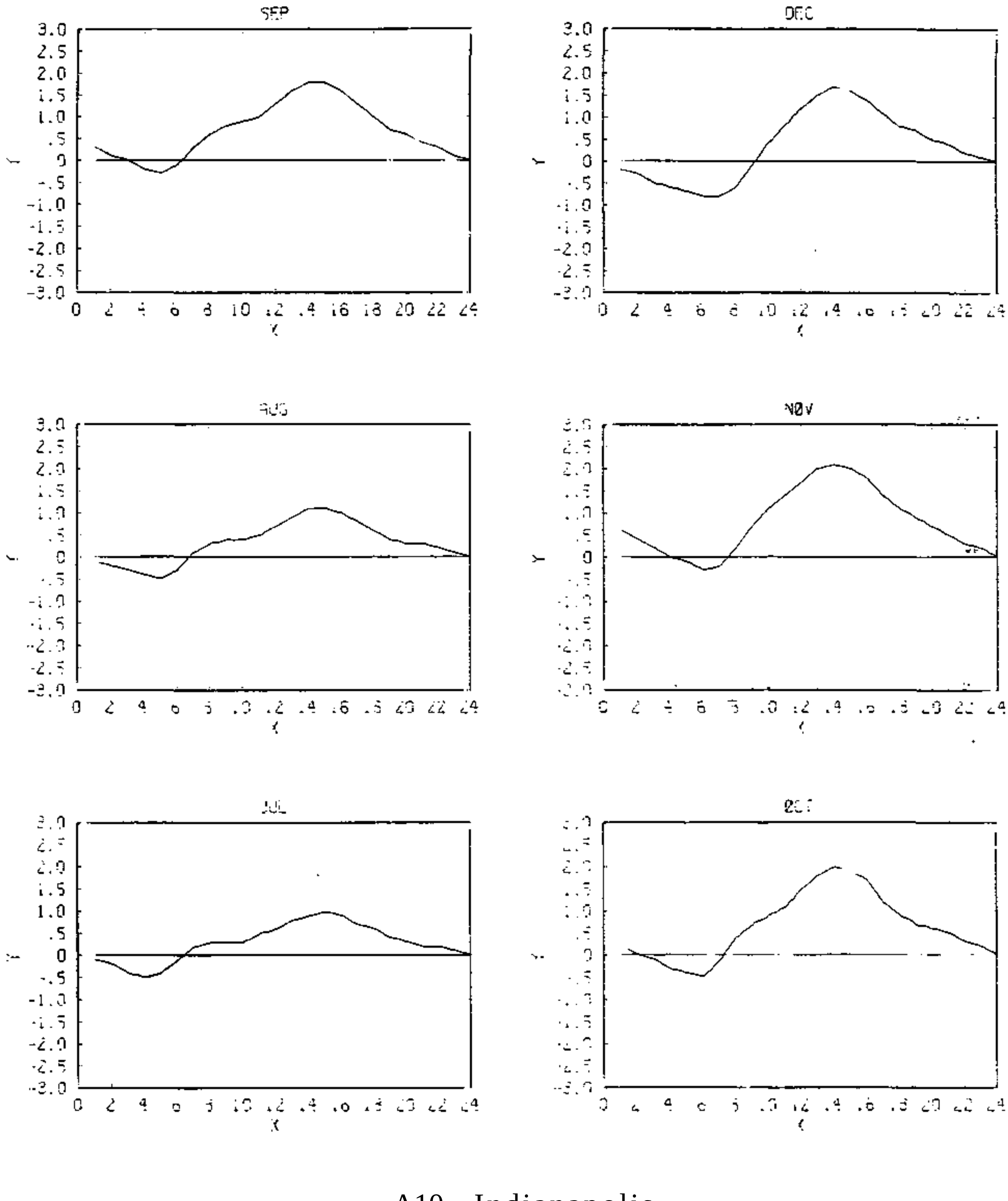
A 7. Flint



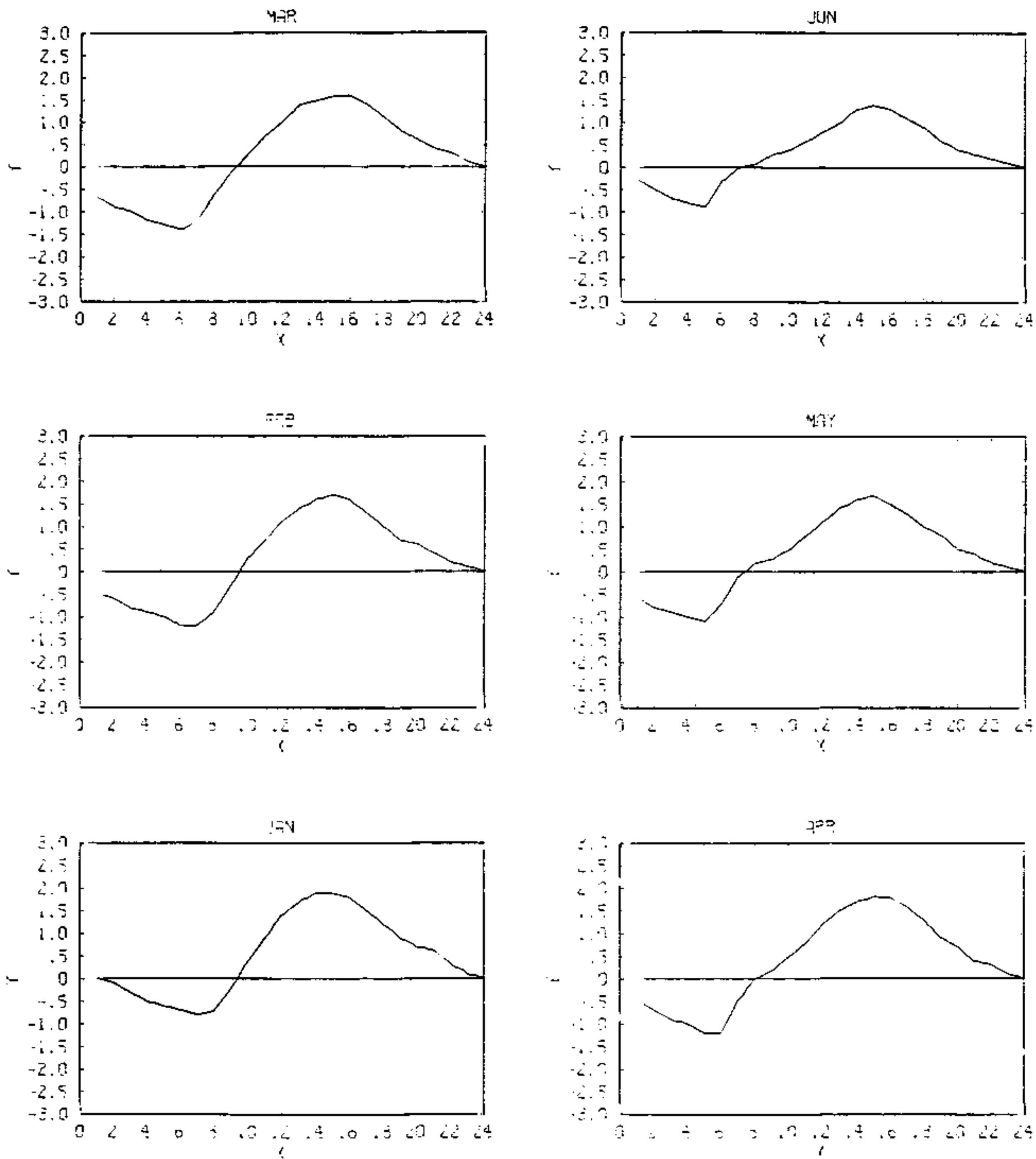
A 8. Flint



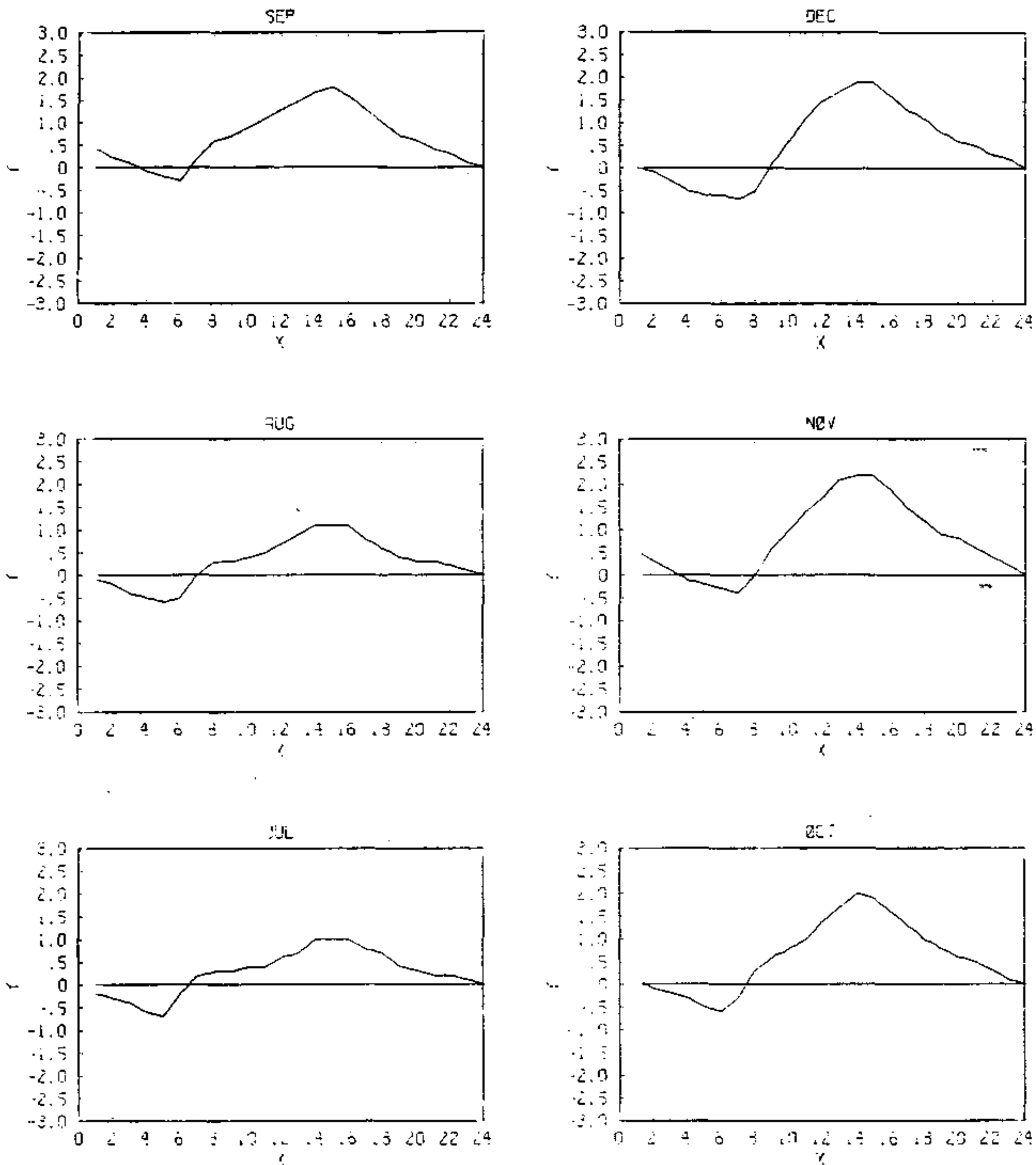
A 9. Indianapolis



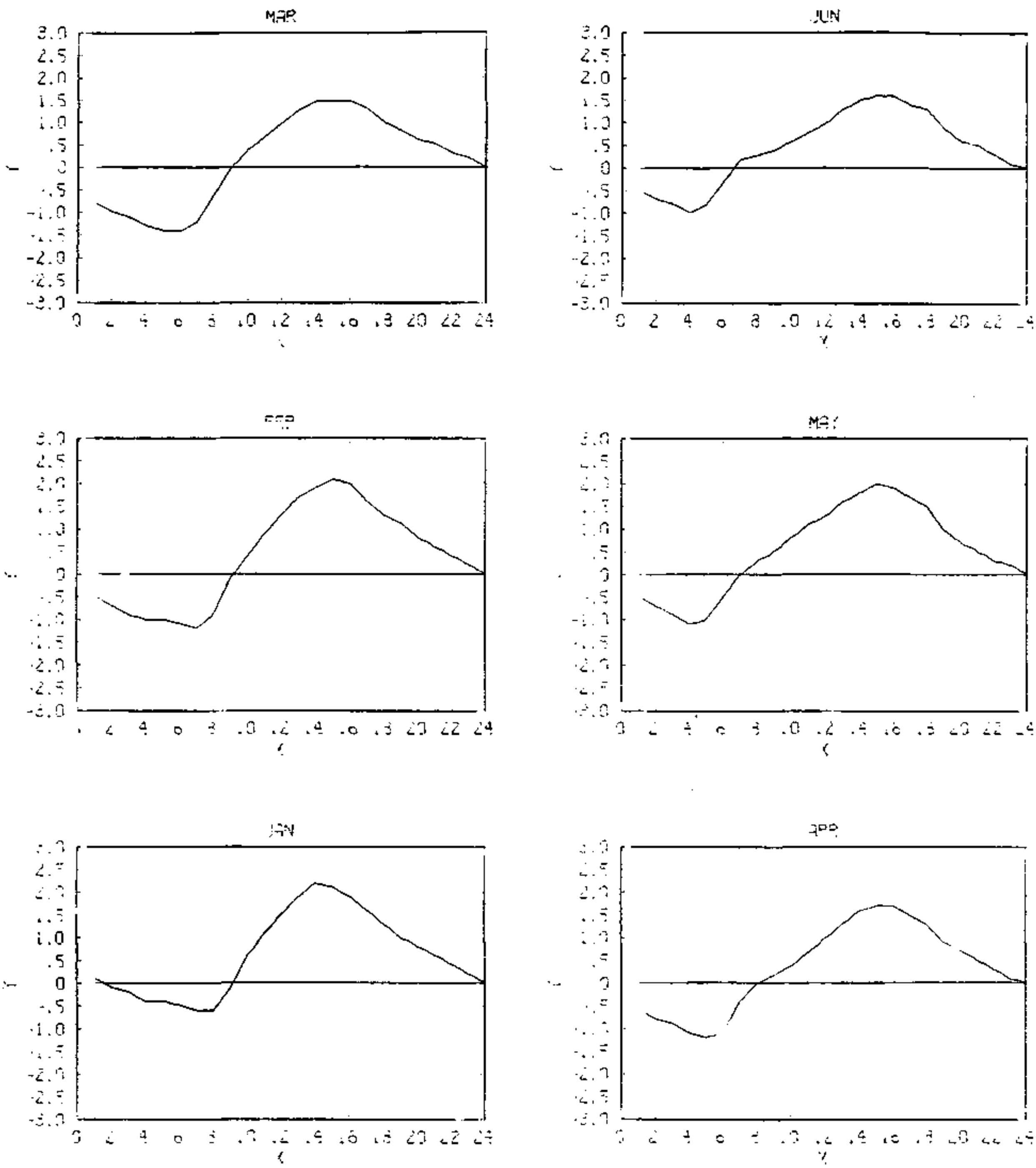
A10. Indianapolis



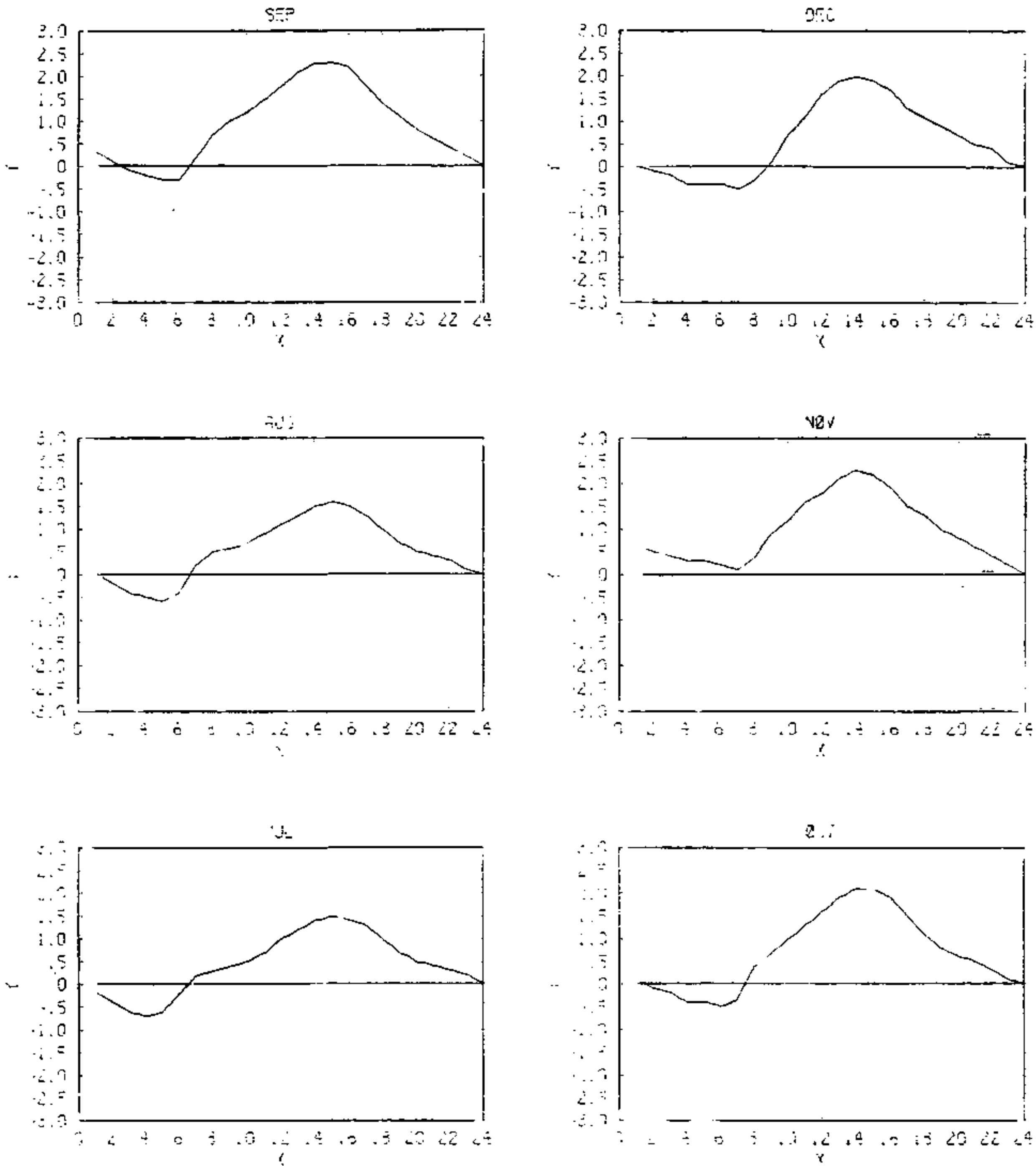
A11 . Peoria


SEP
DEC
AUG
NØV
JUL
3.0
2.5
2.0
1.5
1.0
.5
0
-.5
-1.0
-1.5
-2.0
-2.5
-3.0
0 2 4 6 8 10 12 14 16 18 20 22 24
X

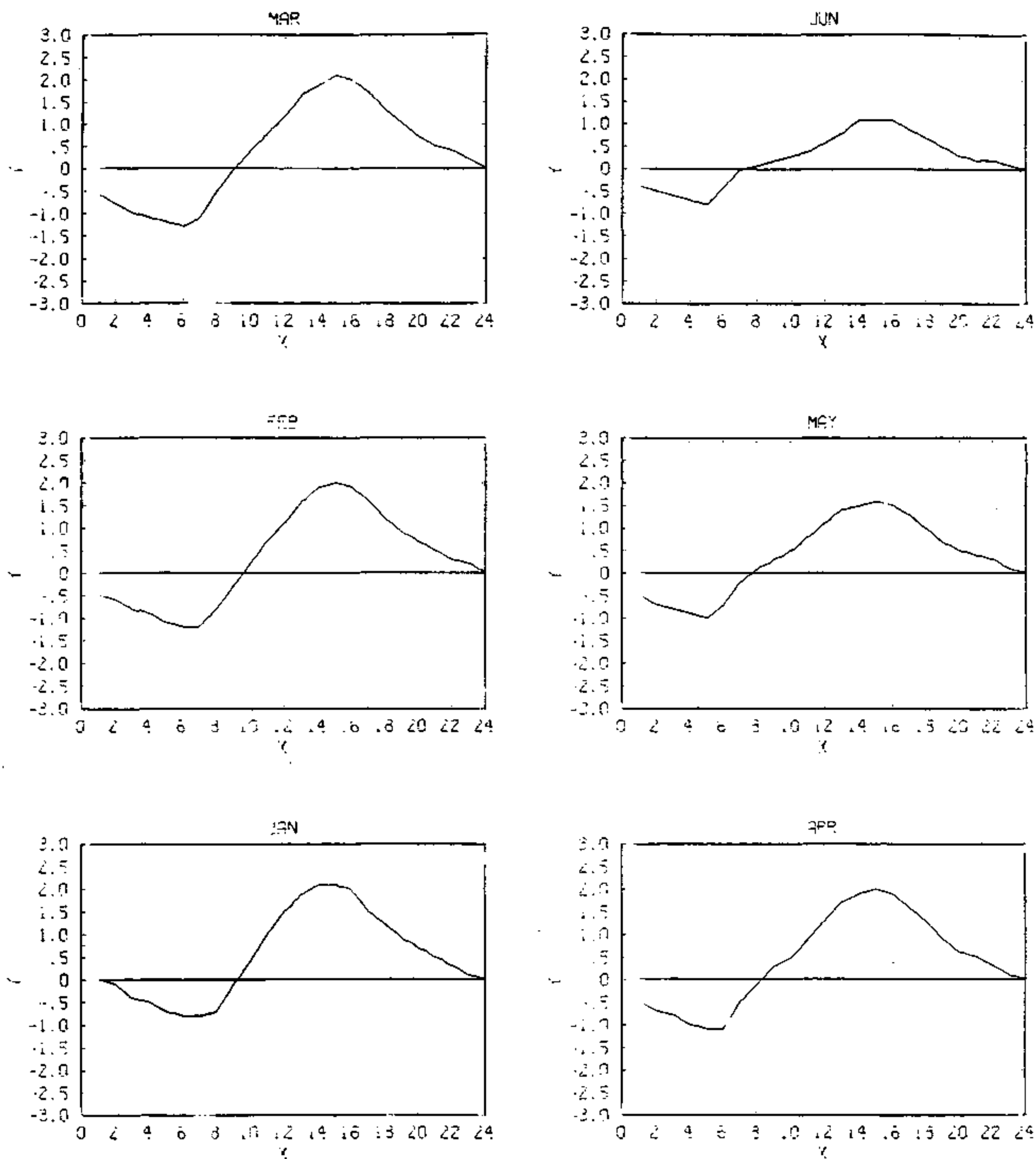
A12. Peoria



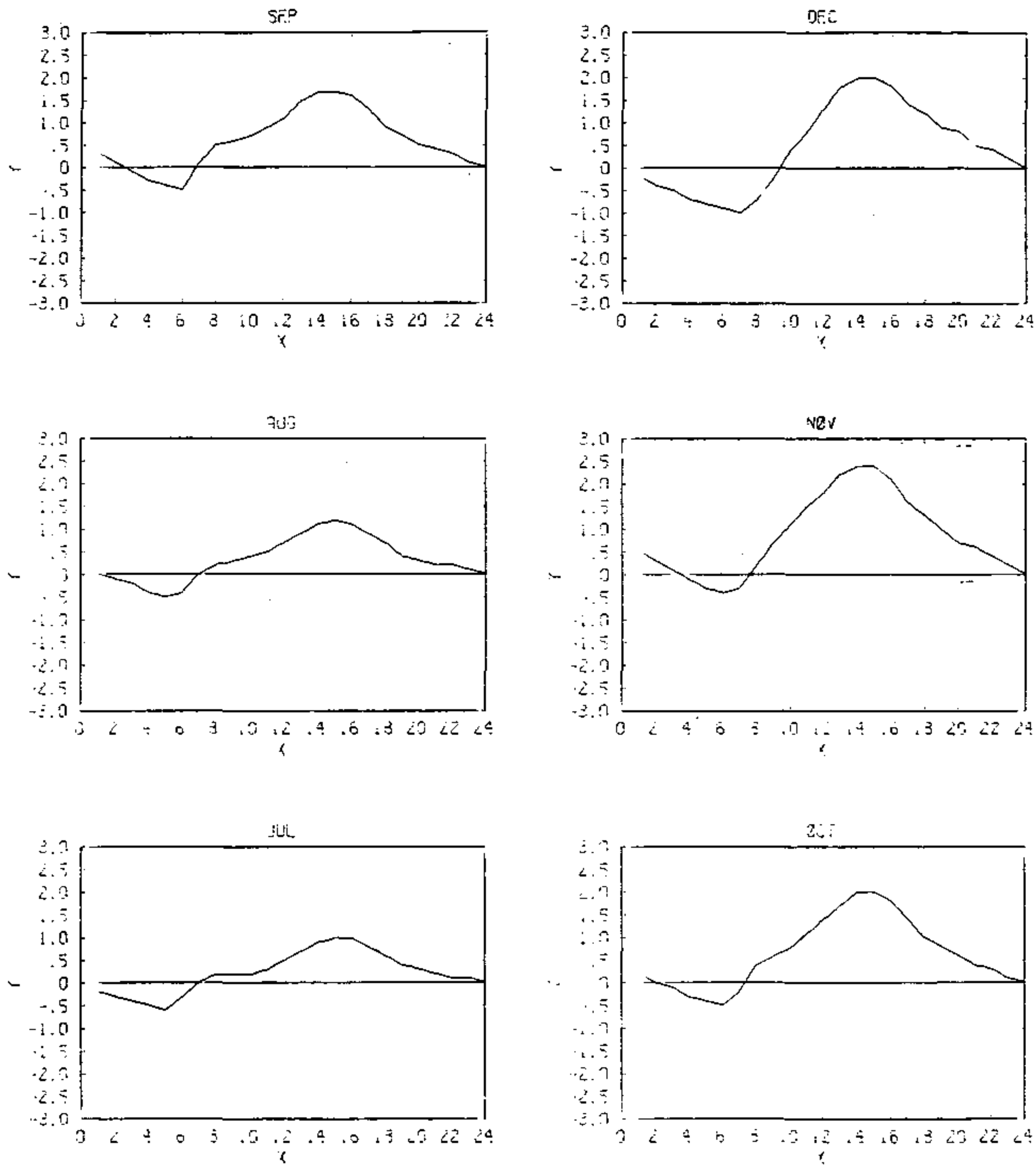
A13. St. Cloud



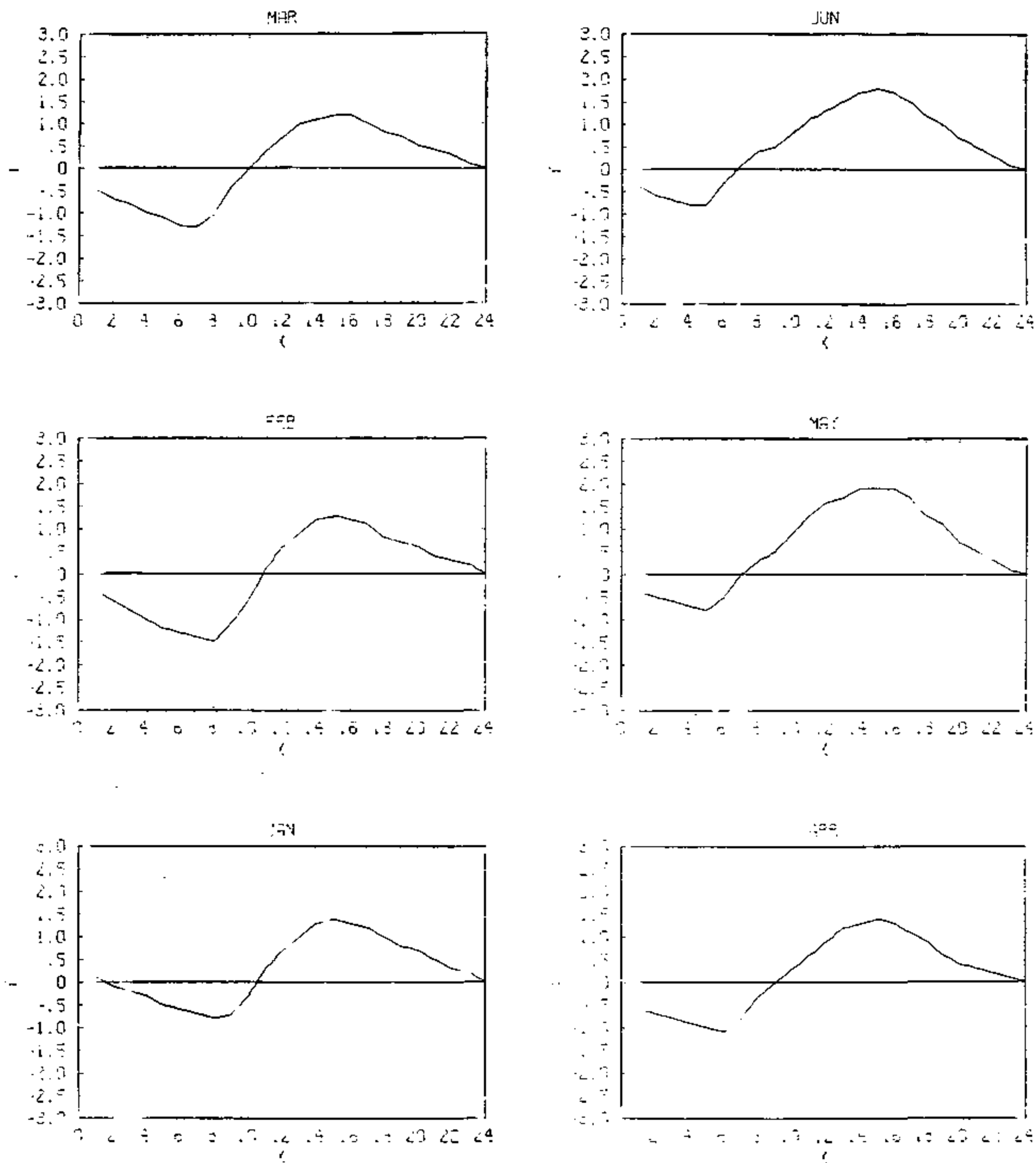
A14. St. Cloud



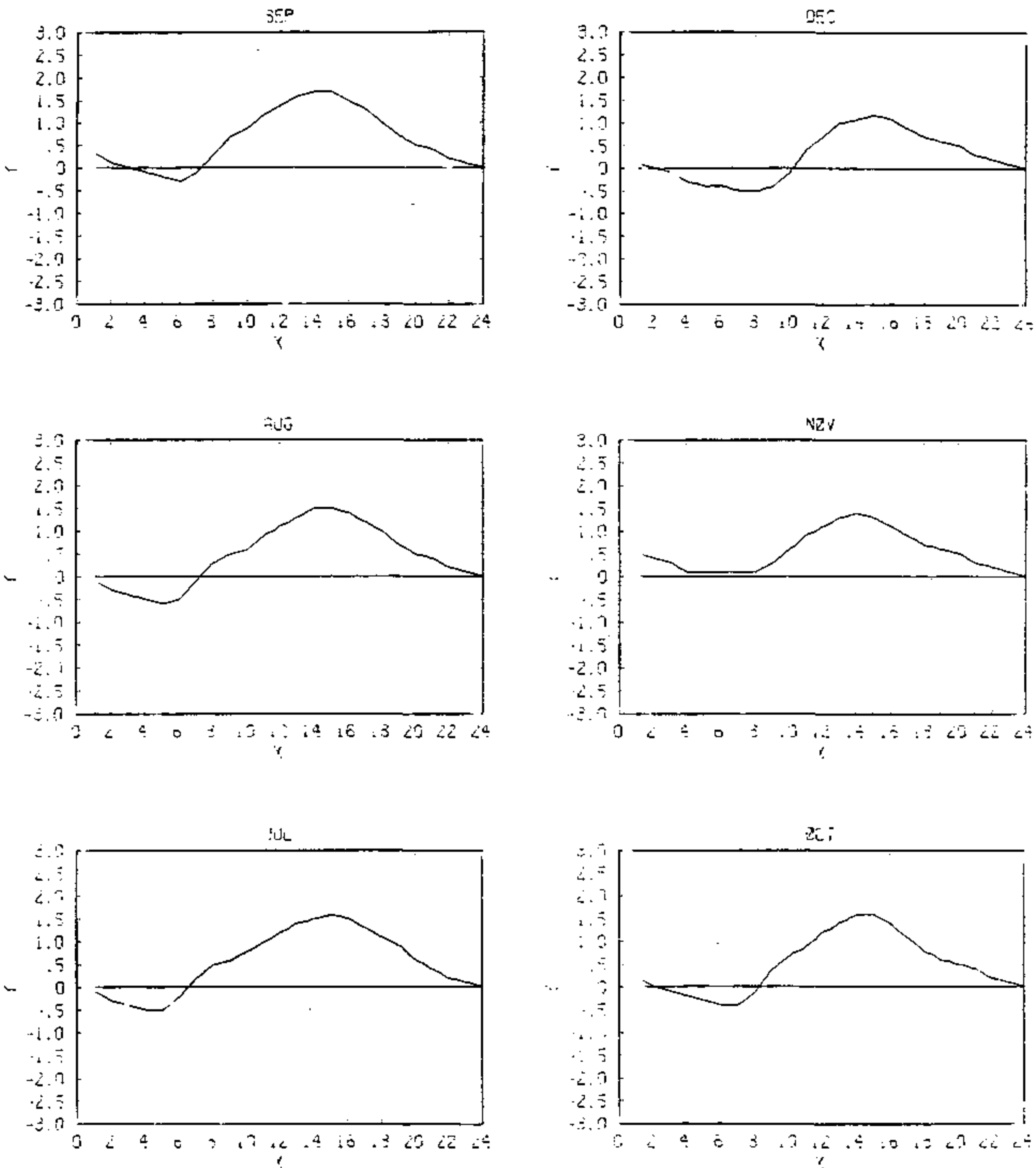
A15. St.. Louis



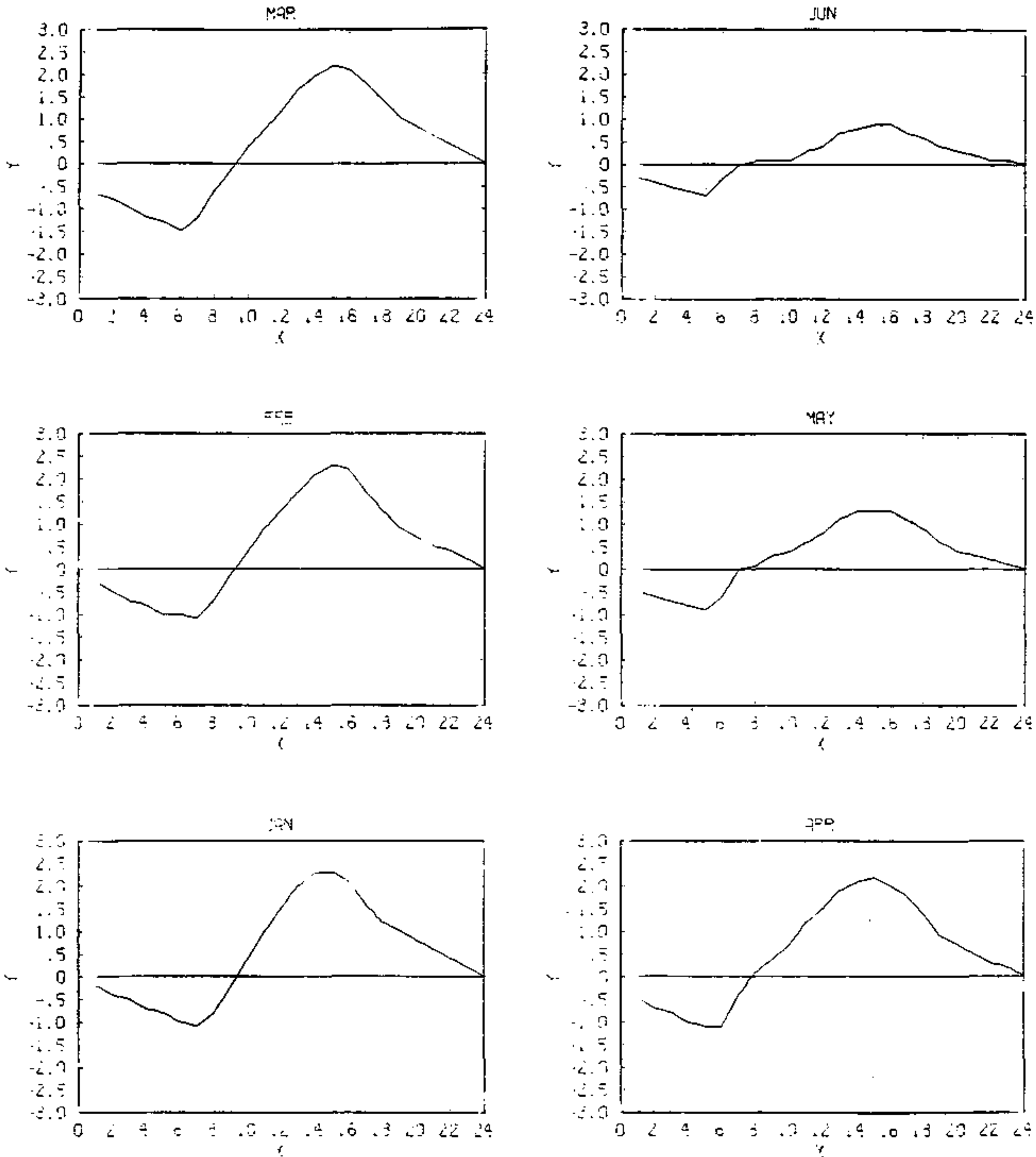
A16. St. Louis



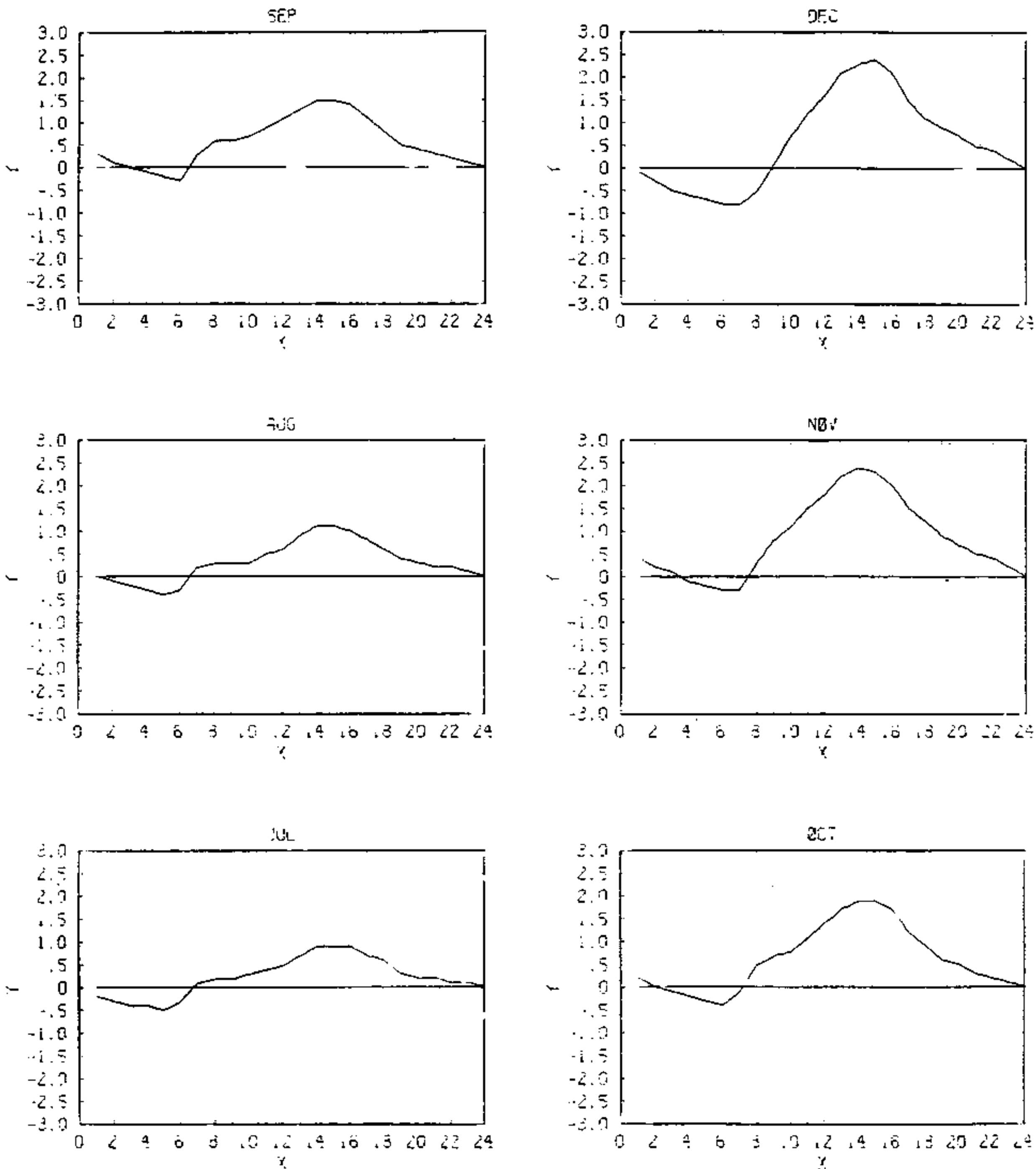
A17. Sault Ste. Marie



A18. Sault Ste. Marie



A19. Springfield



A20. Springfield

APPENDIX B

The following listings are the Fortran 5 programs used in 1) reading and interpolating the tapes of data used in this study, and 2) calculating the means and biases using as input the output from the first program.

```
      PROGRAM  HOURLY(INPUT,OUTPUT,TAPE1,TAPE2,TAPE99)
C  THIS PROGRAM CALCULATES THE 24 MONTHLY MEANS OF A DAY AS
C   DEFINED BY ANY GIVEN 24 HOURS OVER ANY NUMBER OF YEARS.
C  THESE ARE THE ARRAYS $ VARIABLES USED BELCW:
C    GSUM - SUM OF THE 24 HR-DAY MONTHLY MEANS
C    HMAX -
C    HMIN -
C    MEAN -
C    MNTH -
C    TMAX $ TMIN -
C    SUM -
C    TEMP -
C    NYEAR -
C    NDAYS -
      CHARACTER*30 NAME
      REAL  TEMP(768),SUM(24),GSUM(24),HMAX(465),HMIN(465),MEAN(24)
      INTEGER  MAXBER(100),MINBER(100),NDAYS(12),NINE(6)
      DATA  NDAYS/31,28,31,30,31,30,31,31,30,31,30,31/,GSUM/24*0.0/
      DATA  N9S/0/,M9S/0/
C  INITIALIZE ID, 1ST YEAR, NYEAR, AND MNIH INTERACTIVELY.
      PRINT*,'ENTER STATION ID NUMBER:'
      READ*,ID
      PRINT*,'ENTER THE STATION NAME (30 LETTERS MAX):'
      READ(*,111) NAME
      PRINT*,'ENTER THE NUMBER OF THE 1ST FULL YEAR:'
      READ*,N1STYR
      PRINT*,'ENTER THE NUMBER OF YEARS OVER WHICH'
      PRINT*,'THE MEANS SHOULD BE CALCULATED:'
      READ*,NYEAR
      PRINT*,'ENTER THE NUMBER OF THE MONTH'
      PRINT*,'BEING CONSIDERED (1,2,3,...,12):'
      READ*,MNTH
      NLASTYR=N1STYR+NYEAR-1
      N1ST=N1STYR-1900
      ND=NDAYS(MNTH)+1
      LINES=4*ND-1
      M=24*ND
34    READ(1,113) MCHECK
      IF(MCHECK-N1ST) 34,33,34
33    BACKSPACE 1
      DO 6 J=1,NYEAR

C  THIS SECTION SKIPS OVER THOSE DATES NOT WANTED.
25    READ(1, 14,END=1000) MCHECK
      IF(MCHECK-MNTH) 25,24,25
24    DO 23 L=1,5
23    BACKSPACE 1

C  READ INTO TEMP(1-M) THE TEMPERATURES FOR THE 24 HOURS
C   PREVIOUS TO THE CURRENT MONIH (1-24) AND THE 24 HOURS
C   OF EACH DAY OF MONTH. HENCE, M=24*(NDAYS(MNTH)+1). MAXIMUM
```

```
C    VALUE IS 768.

          READ(1, 11,END=1000)  (TEMP(L),L=1,5)
          DO 22 L1=1,LINES
           K=6*L1
           K1=K+5
           READ(1, 12,END=1000)  (NINE(L+1-K),TEMP(L),L=K,K1)
           DO 60 JJ=1,6
60           IF(NINE(JJ).EQ.9)  N9S=N9S+1
22        CONTINUE
          READ(1,13,END=1000)  TEMP(M)


          DO 8 K=1,24
8         SUM(K)=0.0

          DO 3 K=1,NDAYS(MNTH)

C  FIND MAX $ MIN OF THE 24 HR-DAY PERIODS FOR 1 DAY.

          DO 2 N=1,24
           N2=(N+1)+24*(K-1)
           NN=N2+23
           TMAX=TEMP(N2-1)
           TMIN=TMAX
           DO 1 I=N2,NN
            TMAX=AMAX1(TMAX,TEMP(I))
            TMIN=AMIN1(TMIN,TEMP(I))
1          CONTINUE

C  FIND MEAN FOR EACH FOR THE 24 HR-DAY PERIODS FOR 1 DAY.

           MEAN(N)=(TMAX+TMIN)/2.0
2         CONTINUE

C  STORE MID TO MID'S MAX $ MIN FOR HISTOGRAM SUBROUTINE.

          NHIS=K+NDAYS(MNTH)*(J-1)
          HMAX(NHIS)=TMAX
          HMIN(NHIS)=TMIN

C  SUM THE 24 HR-DAY MEANS OVER THE NDAYS(MNTH).

          DO 4 K1=1,24
4         SUM(K1)=SUM(K1)+MEAN(K1)

3         CONTINUE

C  SUM THE 24 HR-DAY MONTHLY MEANS OVER THE NYEARS.

          DO 5 K=1,24
```

```
5     GSUM(K)=GSUM(K)+SUM(K)/FLOAT(NDAYS(MNTH))

C SKIP A FEW DAYS TO ENSURE THAT MARCH 29 IS NOT INCLUDED.
      DO 40 K=1,4
40    READ(1,113) MCHECK

6     CONTINUE

C  CALCULATE THE NYEAR-YR. 24 MEANS AND DIFFERENCES FROM MID,
C   USING TEMP(1-24), TEMP(25-48) AGAIN AS STORAGE FOR THE
C   NYEAR-YR. 24 MEANS AND DIFFERENCES OF 1 - MID, 2 - MID,
C   ETC. (INCLUDING MID - MID=0), RESPECTIVELY.
       TEMP(24)=GSUM(24)/FLOAT(NYEAR)
      DO 9 J=1,23
       TEMP(J)=GSUM(J)/FLOAT(NYEAR)
9      TEMP(J+24)=TEMP(J)-TEMP(24)

C  WRITE OUT STATION ID INFO.,WHICH MONTH OVER WHICH YEARS WERE
C   CALCULATED, AND THE NUMBER OF MISSING TEMPS. THAT WERE
C   INTERPOLATED. ALSO, WRITE OUT THE RESULTS.
      WRITE(99,112) ID,NAME,N1STYR,NLASTYR,MNTH,N9S
      WRITE(99,10) (TEMP(J),J=1,12)
      WRITE(99,10) (TEMP(J),J=13,24)

      WRITE(99,10) (TEMP(J),J=25,36)
      WRITE(99,10) (TEMP(J),J=37,47)

C  THIS SECTION READS THE REAL MAXS AND MINS, AND CALCULATES THE
C   DIFFERENCES OF THE 24 NYEAR HR-DAY MEANS AND THE REAL NYEAR MEAN.

35    READ(2,113) MCHECK
      IF(MCHECK-N1ST) 35,36,35
36    BACKSPACE 2

      GSUM(1)=0.0
      DO 32 L=1,NYEAR

26    READ(2,18,END=1000) MCHECK
      IF(MCHECK-MNTH) 26,27,26
27    BACKSPACE 2

       SUM(1)=0.0
       ND=NDAYS(MNTH)
       DO 31 J=1,NDAYS(MNTH)
        READ(2,19,END=1000) TMAX,TMIN
         IF(TMAX.EQ.999..OR.TMIN.EQ.999.) THEN
           ND=ND-1
           M9S=M9S+1
           TMAX=0.0
           TMIN=0.0
```

```
        ENDIF
31      SUM(1)=SUM(1)+TMAX+TMIN

      GSUM(1)=GSUM(1)+SUM(1)/(2.0*FL0AT(ND))

      DO 41 K=1,2
41    READ(2,113) MCHECK

32    CONTINUE
      TEMP(48)=GSUM(1)/FLOAT(NYEAR)

      DO 20 J=1,24
20      TEMP(J+48)=TEMP(J)-TEMP(48)

      WRITE(99,110) TEMP(48),M9S
      WRITE(99,10) (TEMP(J),J=49,60)
      WRITE(99,10) (TEMP(J),J=61,72)

C  FIND THE HISTOGRAM VALUES (AND/OR GRAPHS) FOR THE MAXS $
C   MINS. WRITE THE RESULTS OUT IN SUBROUTINE HISTGM OR WRITE
C   THE RESULTS OUT BELOW.

      N=NDAYS(MNTH)«NYEAR
      CALL   HISTGM(HMAX,N,MAXBER,NCLAS1,PMIN1,SMAX1)
      CALL   HISTGM(HMIN,N,MINBER,NCLAS2,PMIN2,SMAX2)

C   WRITE OUT HISTGM RESULTS HERE???????
C   THE CLASSES ARE AS FOLLOWS:
C    HIGHEST CLASS... MAX-2 < TEMP < OR EQUAL TO MAX ;
C    NEXT HIGHEST... MAX-4 < TEMP < OR EQ. TO MAX-2;
C    . . . LOWEST... MAX-RANGE < OR EQ. TO TEMP < OR EQ. MAX-RANGE+2.
C
C   HENCE, MAXBER(1) = NUMBER IN HIGHEST CLASS, MAXBER(2) =
C    NUMBER IN NEXT HIGHEST, ETC. SAME FOR MINBER ARRAY.
      WRITE(99,16) SMAX1,PMIN1
      DO 200 J=1,NCLAS1
200    WRITE(99,15) MAXBER(J)
      WRITE(99,17) SMAX2,PMIN2
      DO 201 J=1,NCLAS2
201    WRITE(99,15) MINBER(J)
10    FORMAT(/12F6.1)
110   FORMAT(/F6.1,' REAL MEAN',' NO. MISSING R*,I3)
111   FORMAT(A10)
112   FORMAT('1',I6,1X,A30,1X,'FOR',1X,I4,'-',I4,1X,»MNTH  ',I2,1X,
     C  '#  MISSING H',I3)
113   F0RMAT(I2)
11    FORMAT(14X,5(4X,F4.0))
12    FORMAT(6X,6(3X,I1,F4.0))
13    F0RMAT(10X,F4.0)
14    F0RMAT(2X,I2)
```

```
15      FORMAT(I4)
16      FORMAT(/F7.2,' MAXIMUM OF MAXS ',F7.2,' MINIMUM OF MAXS')
17     FORMAT(/F7.2,'   MAXIMUM OF MINS ',F7.2,' MINIMUM OF MINS')
18      FORMAT(2X,I2)
19      FORMAT(6X,2F4.0)

1000  STOP
      END
      SUBROUTINE HISTGM(X,N,MEMBER,NCLASS,P,S)
C ARGUMENTS:
C X   REAL ARRAY, DIMENSION AT LEAST N, HOLDING THE VECTOR OF
C     RAW DATA FOR WHICH A FREQUENCY PLOT IS REQUIRED.
C NCLASS INTEGER; THE NO. OF CLASSES TO BE USED IN THE HISTO-
C     GRAM.
C N   INTEGER; THE NO. OF OBSERVATIONS.
C CLASS  CLASS INTERVAL.
C
C NOTE THAT THE MAXIMUM NO. OF ITEMS IN ANY ONE CLASS IS 100.
C   TO INCREASE OR DECREASE THIS, CHANGE THE DIMENSION OF
C    *MEMBER*.
C
      DIMENSION X(N),MEMBER(100)
      DATA IB0RD/1HI/,ISTAR/1H*/,CLASS/2.0/
C
C FIND MINIMUM AND MAXIMUM OF X( ).
C
      S=X(1)
      P=S
      DO 1 I=2,N
      IF(X(I).GT.S) S=X(I)
      IF(Xd).LT.P) P=X(I)
1     CONTINUE
C
C FIND RANGE AND NCLASS CLASSES.
C
      RS=AMOD(S,2.0)
      RP=AMOD(P,2.0)
      IF(RS.NE.O.O.AND.RP.NE.O.O) THEN
        S=S+1.0
        P=P-1.0
       ELSE IF(RS.NE.O.O) THEN
        S=S+1.0
       ELSE IF(RP.NE.O.O) THEN
        P=P-1.0
      ENDIF
      NCLASS=IFIX(S-P)/2
C
C SET MEMBERSHIP OF EACH CLASS TO ZERO.
C
      DO 100 I=1,NCLASS
100   MEMBER(I)=0
```

```
C
C DETERMINE NO. IN EACH CLASS.
C
      BOTTOM=S
      DO 2 I=1,NCLASS
      T0P=BOTTOM
      BOTTOM=TOP-CLASS
      IF(I-NCLASS) 10,11,10
10    DO 12 J=1,N
      IF(X(J).GT.BOTTOM.AND.X(J).LE.TOP) MEMBER(I)=MEMBER(I)+1
12    CONTINUE
      GO TO 2
C
C LAST CLASS IS SPECIAL CASE.
C
11    DO 13 J=1,N
      IF(X(J).GE.BOTTOM.AND.X(J).LE.TOP) MEMBER(I)=MEMBER(I)+1
13    CONTINUE
2     CONTINUE
C
C THIS SECTION IS OPTIONAL!!!!!!!!
C PRINT HISTOGRAM ACROSS PAGE. IFIRST SCALE ELEMENTS OF
C  MEMBER TO GET THE BEST FIT IN 100 COLUMNS WIDTH.
C
C      M=MEMBER(1)
C      DO 3 I=2,NCLASS
C      IF(MEMBER(I).GT.M)  M=MEMBER(I)
C3     CONTINUE
C      SCALE=100.0/FLOAT(M)
C      WRITE(*,7) SCALE
C      P=S+0.5*CLASS
C      DO 5 I=1,NCLASS
C      P=P-CLASS
C      M=MEMBER(I)
C      PERC=M/FLOAT(N)*100.0
C      K=INT(M*SCALE+0.5)
CC
CC CHECK FOR K=0 AND ACT ACCORDINGLY.
CC
C      IF(K) 23,21,23
C21    WRITE(*,20) IBORD
C   WRITE(*,6)   M,PERC,IBORD
C      WRITE(*,24) P,IBORD
C      GO TO 5
C23    WRITE(*,20) IBORD,(ISTAR,J=1,K)
C      WRITE(*,6) M,PERC,IBORD,(ISTAR,J=1,K)
C      WRITE(*,24) P,IBORD,(ISTAR,J=1,K)
C      WRITE(*,20) IBORD,(ISTAR,J=1,K)
C5     CONTINUE
C6     FORMAT(1H,I4,3X,F10.4,2X,10A1)
C7   FORMAT(18HOSCALING   FACTOR = ,F10.4///7H NUMBER,5X,7HPERCENT/1H,
```

```
C          1    5X,8HMIDPOINT//)
C20         FORMAT('        ',19X,101A1)
C24         FORMAT(1H,F10.4,9X,101A1)

            RETURN
            END
```

```
      PROGRAM  RTAPLAG(TAPE1=/500,TAPE90,TAPE51)
      INTEGER  I(19),MARK(6),ITEMP(l8),ID(3),IHR(l8),IX(4),IY(4)
      DATA MARK/6*0/,NYR/1950/,NL/15/
C     PRINT*,'ENTER THE FIRST YEAR WANTED:•
C     READ*,NYR
        NYEAR=NYR-1900-1
C     PRINT*,'ENTER THE NUMBER OF YEARS TO BE READ:'
C     READ*,NL
      NLINES=NL*4*366+4
33     READ(1,4999) MCHECK
       IF(MCHECK-NYEAR) 33,32,33
32    DO 10 K=1,1440
10    READ(1,5000) JUNK
      DO 11 L=1,NLINES
      READ(1,5001)  (I(J),J=1,19)
       DO 12 J=3,18,3
        IFLD=I(J)
        ISGN=I(J+1)
        CALL SIGNCK(IFLD,ISGN)
12     I(J)=IFLD
11    WRITE(90,5002)  I(1),(I(J),I(J+1),J=2,17,3)
4999  F0RMAT(9X,I2)
5000  F0RMAT(A1)
5001  FORMAT(9X,A6,6(A2,13X,I2,A1,62X))
5002  FORMAT(A6,6(1X,A2,1X,I4))
      REWIND 90
      READ(90,9)  (ITEMP(J),J=1,6)
      DO 876 J=1,6
      IF(ITEMP(J).EQ.9999)  THEN
       PRINT*,'CHECK 1ST LINE OF INPUT FILE FOR 9999S!'
       GO TO 1000
      ENDIF
876   CONTINUE
      BACKSPACE 90
      READ(90,7)  ID(1),(IHR(J),ITEMP(J),J=1,6)
      WRITE(51,8)  ID(1),(IHR(J),MARK(J),ITEMP(J),J=1,6)
      READ(90,7)  ID(2),(IHR(J),ITEMP(J),J=7,12)
4     READ(90,7,END=100)  ID(3),(IHR(J),ITEMP(J),J=13,18)
      J=7
1     IF(ITEMP(J).EQ.9999)  THEN
        IX(1)=J-2
        IX(2)=J-1
        IY(1)=ITEMP(J-2)
        IY(2)=ITEMP(J-1)
        K=J+1
        II=3
```

```
5         IF(ITEMP(K).NE.9999) THEN
             IX(II)=K
             IY(II)=ITEMP(K)
             IF(II.EQ.4) GO TO 6
             II=II+1
             K=K+1
           ELSE
             K=K+1
          ENDIF
          GO TO 5
6         CALL INTERP(IX,IY,4,J,IYINT)
          ITEMP(J)=IYINT
          MARK(J-6)=9
          J=J+1
        ELSE
          J=J+1
       ENDIF
       IF(J.EQ.13) GO TO 2
       GO TO 1
2      WRITE(51,8) ID(2),(IHR(J),MARK(J-6),ITEMP(J),J=7,12)
       DO 3 J=1,6
        ITEMP(J)=ITEMP(J+6)
        ITEMP(J+6)=ITEMP(J+127
        IHR(J)=IHR(J+6)
        IHR(J+6)=IHR(J+12)
3       MARK(J)=0
       ID(1)=ID(2)
       ID(2)=ID(3)
       GO TO 4
100    WRITE(51.8)  ID(2),(IHR(J),MARK(J-6),ITEMP(J),J=7,12)
7       F0RMAT(A6,6(1X,A2,1X,I4))
8       F0RMAT(A6,6(1X,A2,I1,I4))
9       F0RMAT(6X,6(4X,I4))
1000   STOP
       END
       SUBROUTINE SIGNCK(IFLD,ISGN)
       DIMENSION IP(10),MIN(10),NUM(10)
       DATA IP/1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1H</
       DATA MIN/1HJ,1HK,1HL,1HM,1HN,1H0,1HP,1HQ,1HR,1H1/
       DATA NUM/1,2,3,4,5,6,7,8,9,0/,IAST/1H*/,MM/1H /
       IF(ISGN.EQ.IAST.OR.ISGN.EQ.MM) GO TO 16
       DO 14 K=1,10
       IF(ISGN.EQ.IP(K)) GO TO 20
       IF(ISGN.EQ.MIN(K)) GO TO 22
14     CONTINUE
16     IFLD=9999
       RETURN
20     IFLD=IFLD*10+NUM(K)
       RETURN
```

```
22     IFLD=-(IFLD*10+NUM(K))
       RETURN
       END
       SUBROUTINE INTERP(IX,IY,N,IXT,IYINT)
       DIMENSION IX(N),IY(N)
        YINT=0
       DO 10 I=1,N
        EMP=IY(I)
        DO 11 J=1,N
         IF(I.NE.J) EMP=EMP*FLOAT(IXT-IX(J))/FLOAT(IX(I)-IX(J))
11      CONTINUE
        YINT=YINT+EMP
10     CONTINUE
       R=AM0D(YINT,1.0)
       IF(R.GE..5) YINT=YINT+1.0
       IYINT=INT(YINT)
       RETURN
       END
```

REFERENCES

Baker, D. G.; 1975: Effect of Observation Time on Mean Temperature Estimation, J. Appl. Meteor., 14, 471-476.

Bigelow, F. H. ; 1909: Report on the Temperatures and Vapor Tensions of the United States, Bull. S.W.B., No. 408, U.S. Weather Bureau, Washington, D.C.

Blackburn, T.; n.d.: A Practical Method of Correcting Monthly Averages to Biases Caused Solely by Differing Times of Observation , mss, National Weather Service, Silver Spring, Maryland.

Calef, W.; 1950: Interdiurnal Variability of Temperature Extremes in the United States, Bull. Amer. Meteor. Soc., 31,300-302.

Changnon, S. A., Jr.; 1975: Illinois Weather and Climate Information - Where to Find It, Illinois State Water Survey Circular 123.

Crowe, P. R.; 1971: Concepts in Climatology, Longman Group Limited, London.

Currey, D. R.; 1974: Continentality of Extratropical Climate. Annals Assoc. Amer. Geographers, 64, 268-280.

Dale, R. F.; Nelson, W. L. and McGarrahan, J. P.; 1983: The Effect of Bias in Divisional and State Mean Temperatures on Weather-Crop Yield Model Predictions - A Case Study in Indiana, J. Clim. and Appl. Meteor., 22, 1942-1852.

Donnel, D. A.; 1912: The Effect of the Time of Observation On Mean Temperatures, Mon. Wea. Rev., 40, 708.

Hartzell, F. Z. ; 1919: Comparison of Methods for Computing Daily Mean Temperatures, Mon. Wea. Rev., 47, 799-801.

Huschke, R. E.; 1959: Glossary of Meteorology, Amer. Meteor. Soc., Boston, 638 pp.

Landsberg, H. E. ; 1966: Interdiurnal Variability of Pressure and Temperature in the Coterminous United States, U.S. Weather Bureau, Wash. D.C., Tech. Pap. 56, 53pp.

Mitchell, J. M., Jr.; 1953: On the Causes of Instrumentally Observed Secular Temperature Trends, J. Meteor., 10, 244-261.

Mitchell, J. M., Jr.; 1955: The Observation and Forecasting of Daily Maximum and Minimum Temperatures in the Elmendorf Area, Tech. Memo No. 6, Alaskan Weather Center, Air Weather Service.

Mitchell, J. M., Jr.; 1958: Effect of Changing Observation Time on Mean Temperature, Bull. Amer. Meteor. Soc., 39, 83-89.

Mitchell, J. M., Jr.; 1961: The Measurement of Secular Temperature Change in the Eastern United States, U.S. Dept. of Commerce, Weather Bureau Res. Paper No. 43, Washington, D.C., 80 pp.

Nelson, W. L.; Dale, R. F. and Schaal, L. A.; 1979: Non-Climatic Trends in Divisional and State Mean Temperatures - A Case Study in Indiana, J. Appl. Meteor., 18, 750-760.

Nichols, E. S.; 1934: Time Limits of the Day as Affecting Records of Minimum Temperature, Mon. Wea. Rev., 62, 337-343.

Reitan, C. H.; 1974: Frequencies of Cyclones and Cyclogenesis for North America, 1951-1970, Mon. Wea. Rev., 102, 861-868.

Riehl, H.; 1972: Introduction to the Atmosphere, 2nd ed., McGraw-Hill, Inc. New York.

Rosenberg, N.; 1974: Microclimate - The Biological Environment, John Wiley & Sons, New York.

Rumbaugh, W. F.; 1934: The Effect of Time of Observation on Mean Temperature, Mon. Wea. Rev., 62, 375-376.

Schaal, L. A. and Dale, R. F.; 1977: Time of Observation Temperature Bias and "Climatic Change", J. Appl. Meteor., 16, 215-222.

Sumner, A. R.; 1953: Standard Deviations of Mean Monthly Temperatures in Anglo-America, Amer. Geog. Society, 43, 50-59.

Thornthwaite, C. W.; 1948: An Approach Toward a Rational Classification of Climate, Geog. Rev., 38, 55-94.

Trewartha, G. T. and Horn, L. H.; 1980: An Introduction to Climate, McGraw-Hill Book Company, New York.

U.S. Government Printing Office; 1964: Manual of Surface Observations, 7th ed., (WBAN) Circ. N, Washington, D.C.

Visher, S. S.; 1954: Climatic Atlas of the United States, Harvard Univ. Press, Cambridge.

Zishka, K. M. and Smith, P. J.; 1980: The Climatology of Cyclones and Anticyclones over North America and Surrounding Ocean Environs for January and July, 1950-77, Mon. Wea. Rev., 108, 387-401.